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Skylab Reuse Study

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SKYLAB REUSE STUDY

NAS8-32916

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FOREWORD

This document presents results of work performed by the Martin Marietta Corporation and the Bendix Corporation Guidance Systems Division while under contract to NASA George C. Marshall Space Flight Center. This report was prepared as partial fulfillment of Contract NAS8-32916, Skylab Reuse Study. The NASA Contracting Officer's Representative was Cary Rutland of Program Development.

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1.0 INTRODUCTION AND OVERVIEW

This program study defined Skylab Reuse (see Figure 1-1) encompassing habitation and payload requirements, mission and configuration accommodations, assessment of systems reactivation (refurbishment kits), and programmatics/costs. A summary study of objectives and schedule are presented in Figure 1-2.

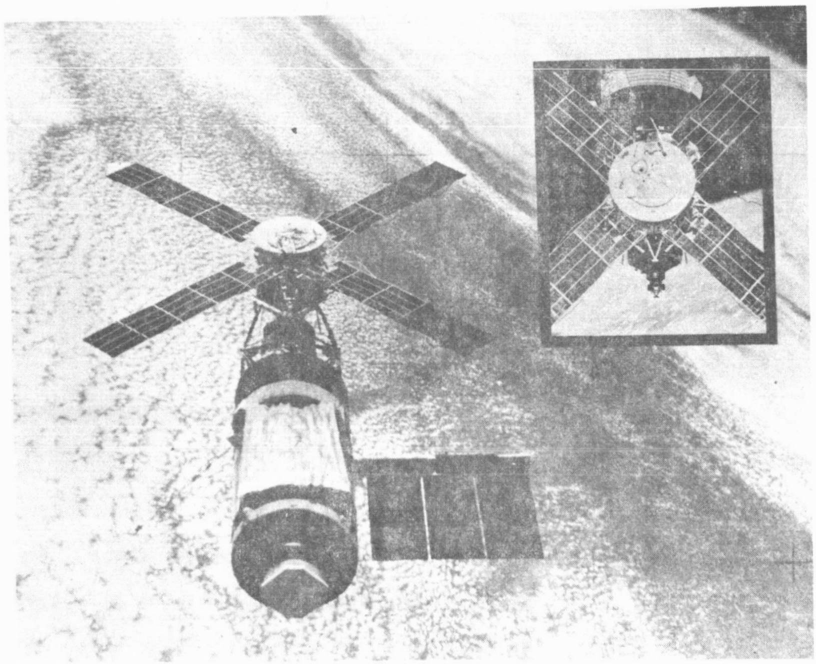


Figure 1-1 Skylab

Martin Marietta and Bendix Corporation were teamed in this effort as they were during the Skylab program. The following Martin Marietta/Bendix efforts were used as a basis for this study.

1974 Skylab Flight Data

- Performed Final Program/Flight Operations Documentation

1974 ASTP Alternate Mission Study (Skylab Contract)

- Evaluated all Systems/Subsystems

1977 MMC/NASA In-House Study

- We Concluded That: Skylab Could Be Reactivated (Crew 3 to 7) Significant Mission Utility Could Be Provided

Also, the results of NASA's 1978 ground interrogation tests were used to establish the status of systems/subsystems.

- Define Payloads & Requirements
- Define Skylab Benefits
  - Habitability
  - Payload Accommodation
    - Primarily Early Payloads
- Define Reactivation
  - Hardware/Software
  - Missions
  - Crew Activities
  - Cost

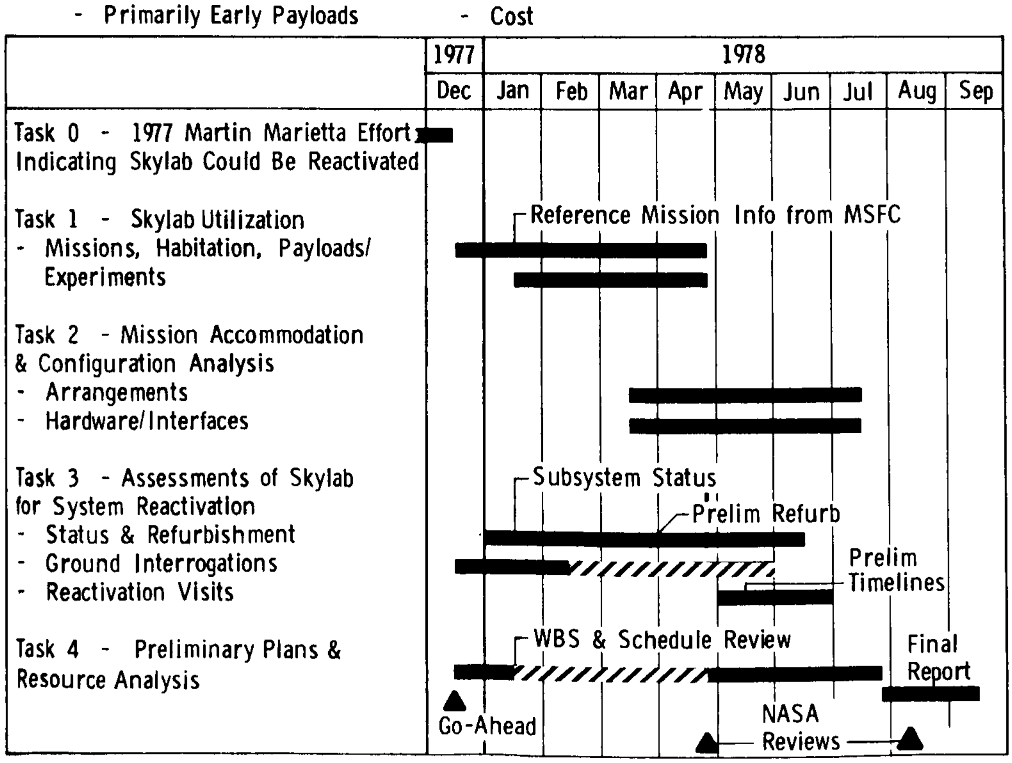


Figure 1-2 Study Objectives and Schedule

Study ground rules were established by MSFC with inputs from JSC and Headquarters. Ground rules related to the schedule are as follows:

Skylab Reboost October 1979 (additional reboost missions to be determined)

25 kW Power Module (PM) available January 1984, Reuse Utilization Begins

Assess Earlier Utilization Prior to Power Module

Program Phases:

Phase I - Initial Ground Interrogations & Definition

Phase II - Reboost/Inspection/Habitability Refurbishment

Phase III- PM/Skylab Dock and Initial Reuse Operations (Shuttle Tended)

Phase IV - Growth and Continuously Manned Operations (Untended)

The study assumes an initial reboost in October 1979 using the Teleoperator Retrieval System. Following refurbishment and resupply in 1982-83, the Power Module is docked to Skylab and operations begin in 1984. (Note: The Power Module will be available prior to early 1984; however, its use with Skylab is assumed then.)

Study ground rules and assumptions encompassing design/operations are as follows:

All basic Skylab subsystems will be considered operational, repairable, or replaceable.

Operations that require Orbiter hardware modifications will be avoided.

Orbiter/Skylab communications subsystems will be compatible with TDRSS.

Current Skylab capability, mission hardware, and scenarios with potential early benefits will be emphasized.

However, future potential will be evaluated to define growth requirements upon initial Skylab configuration and performance.

Operational design life goal of Skylab is Ten-Years from reactivation.

Crew transfer during nominal and rescue operations will be achieved by an Orbiter equipped with a Docking Module.

Skylab operating pressure is nominally five PSIA; Orbiter nominal operating pressure is 14.7 PSIA. Trade studies will be performed to determine the impact of different pressure ratios (Orbiter-to-Skylab).

Existing, minimally modified, and anticipated hardware and components will be used (in that order of preference) as much as possible. Examples of hardware are as follows:

- 25kW Power Module (MSFC baseline as updated)
- Teleoperator (MSFC baseline as updated)
- Manned Maneuvering Unit
- Instrument Pointing System

Ground interrogation of Skylab will be possible during unmanned periods.

Interface Module shall be designed such that Power Module can be detached from Skylab cluster without module shuffling.

Untended (no Orbiter docked to Skylab) manned/unmanned operations will be investigated as a Phase IV operational mode.

Reference altitude for PM/Skylab operations is 230 N. Mi. Study will determine desired altitude for initial reuse operations.

Cost Study Ground Rules Are As Follows:

Costing activity will concentrate on reactivation and refurbishment of Skylab systems and Skylab experiments (Phases I and II);

However, estimates will be made for elements of the Reuse Program through Phase III and the cost impact of Shuttle untended operations if determined to be an attractive mode.

Shuttle flights for Skylab reactivation and operation may be shared with other programs to reduce costs.

STS cost per flight will be in accordance with the NASA Space Transportation System Reimbursement Guide.

Costs will be in 1978 dollars. Cost inflation factors will be per NASA/MSFC.

Costs will be prepared for categories defined in the NASA approved work breakdown structure.

Estimates will exclude NASA institutional costs

Costing will assume a protoflight approach to hardware development.

Parametrically derived estimates based on weight will include a weight contingency of 25%.

Basic cost of GFE hardware (25 kW Power Module, Teleoperator, Spacelab, etc.) will be excluded. Cost of any modifications will be included.

As shown in Figure 1-3, the baseline Skylab Reuse Scenario, as established by NASA, consisted of four phases with emphasis on the first three phases.

The first phase is now underway and has several objectives (Figure 1-4). First, ground interrogation and control of Skylab is being accomplished. At least two things have resulted from this activity. 1) Skylab has been reoriented, resulting in a longer on-orbit lifetime, and 2) Subsystem status has been determined. Subsystems are in good operating condition such that, with consumable resupply (water, N_2,O_2, food, etc), Skylab can be reused. The second objective is to define reactivation hardware, software, analysis, and transportation with their resulting costs for program Phases II, III, and IV. This is the subject of this study. As will be

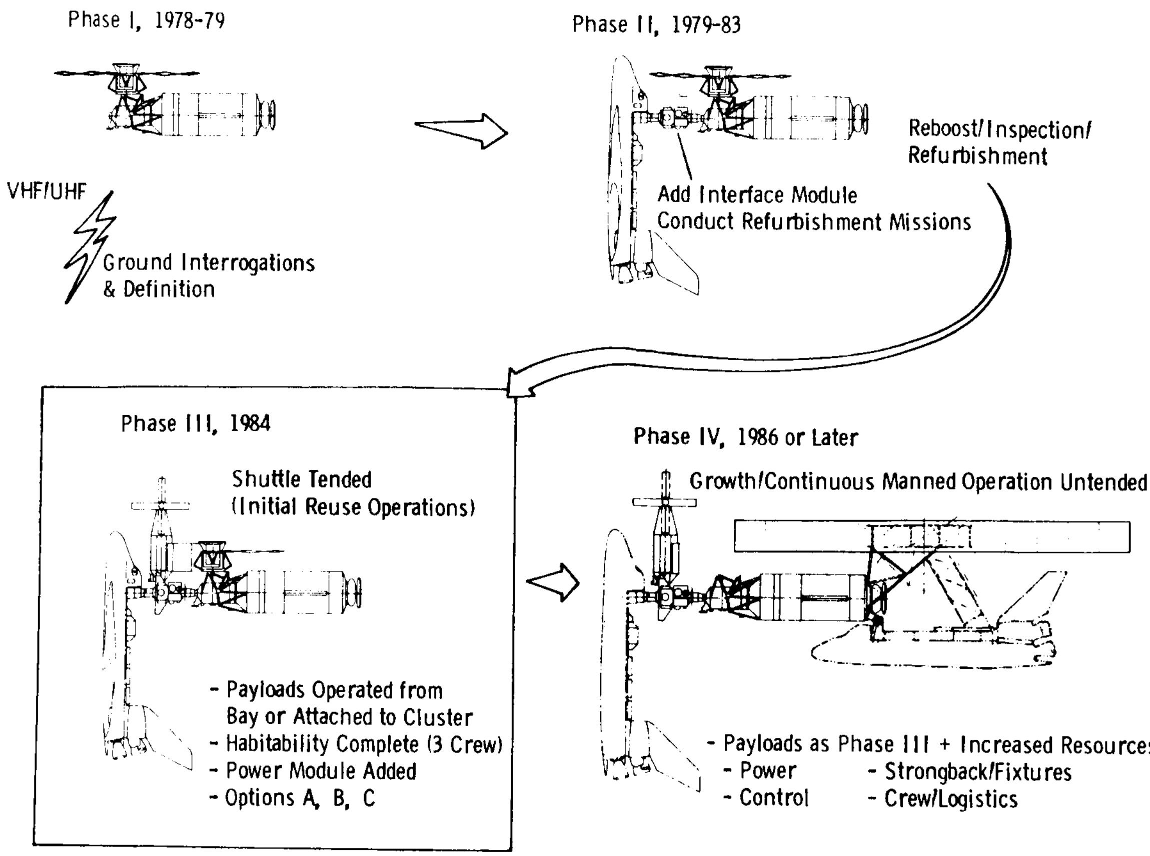


Figure 1-3 Skylab Reuse Scenario--Baseline

- Interrogation/Attitude Control
  - Extend Orbit Lifetime
  - Define Subsystem Status
- Reuse Analysis
  - Systems Engineering/Integration
  - Interface Module Definition
    - Plans
    - Specifications/Interfaces
    - Design
    - Costs/Schedules
- Definition of Reactivation Requirements & Refurbishment Kits
  - Subsystem Repair/Resupply
  - Sustaining Engineering for Subsystems
- Analysis of Payload Requirements/Capabilities
  - Payloads for Skylab Cluster

Objectives

- Scope Reactivation Program
  - Hardware/Software
  - Airborne/Ground
- Extend Orbit Lifetime for Reboost

Figure 1-4 Phase I Activities and Objectives presented later in this report, the reactivation costs are nominal, especially when compared to any new start space station of equivalent capability.

Phase II objectives are shown in the outlined area of Figure 1-5. This phase begins at Skylab Reboost (late 1979) and continues to early 1984. Phase II is the reactivation period during which refurbishment kits are built and flown to Skylab using the Space Shuttle. An Interface Module provides the link between Skylab and the Shuttle, permitting resupply, power, data, fluid, C&W transfers among cluster elements, and later docking of the Power Module and payloads.

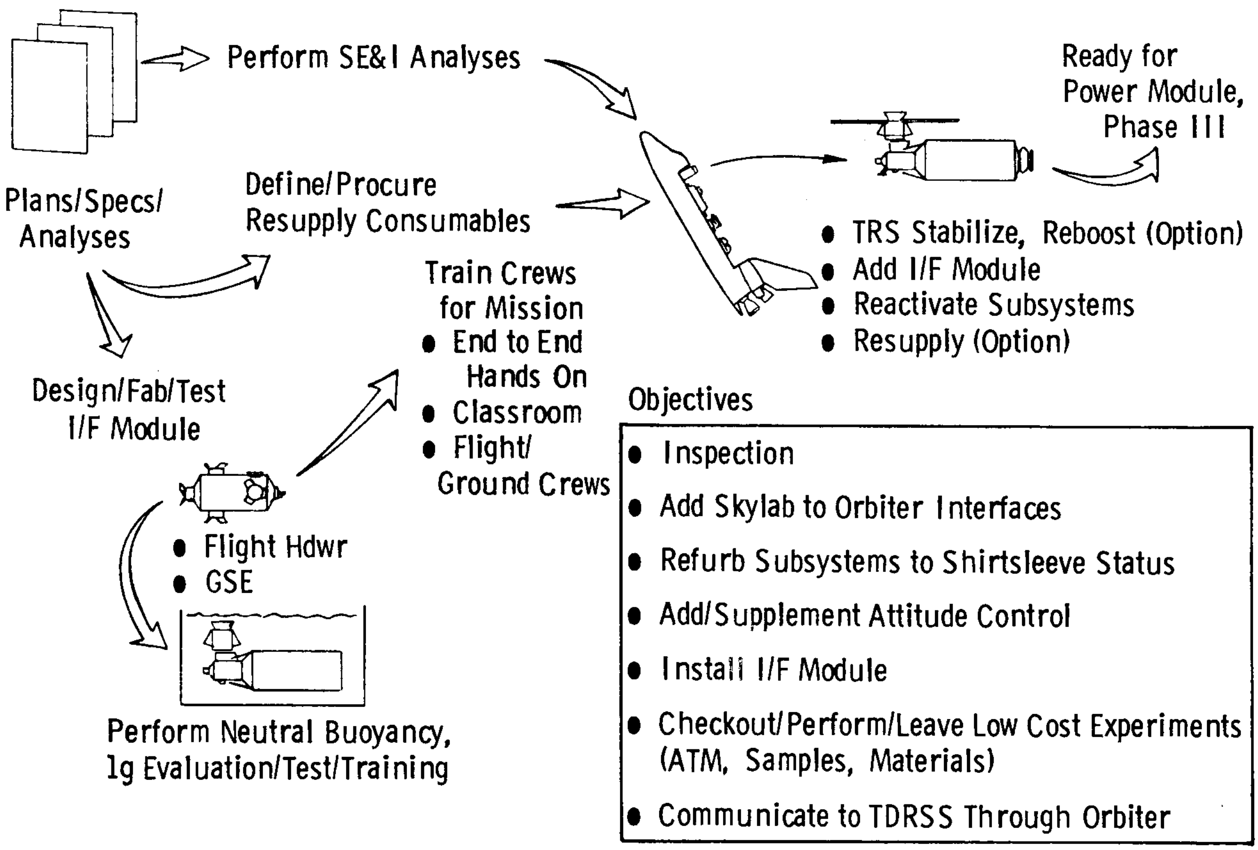


Figure 1-5 Phase II Activities and Objectives

Systems engineering and integration analyses are needed to define combined Skylab, Orbiter, and Interface Module operation. Plans and specifications from Phase I will be redefined and implemented for development of refurbishment kits and the Interface Module. Testing and training will include neutral buoyancy training in the MSFC facility and 1-g evaluations either in the MSFC mockup or the 1-g trainer at JSC. One or two refurbishment flights will be made to reactivate the subsystems. As will be seen later, Shuttle payload weight and length is compatible with carrying the Teleoperator Retrieval System (TRS) to provide stability for docking and, if desired, reboost.

During Phase III (Figure 1-6) the Power Module is docked to Skylab and payload missions begin. Mission operations start in January 1984. Analysis has shown that all payload disciplines can be operated in this mode, either from the Shuttle Payload Bay or attached to the Cluster. As the Phase III missions continue, the Cluster is outfitted for untended operations (manned operations with the Shuttle detached). Autonomous

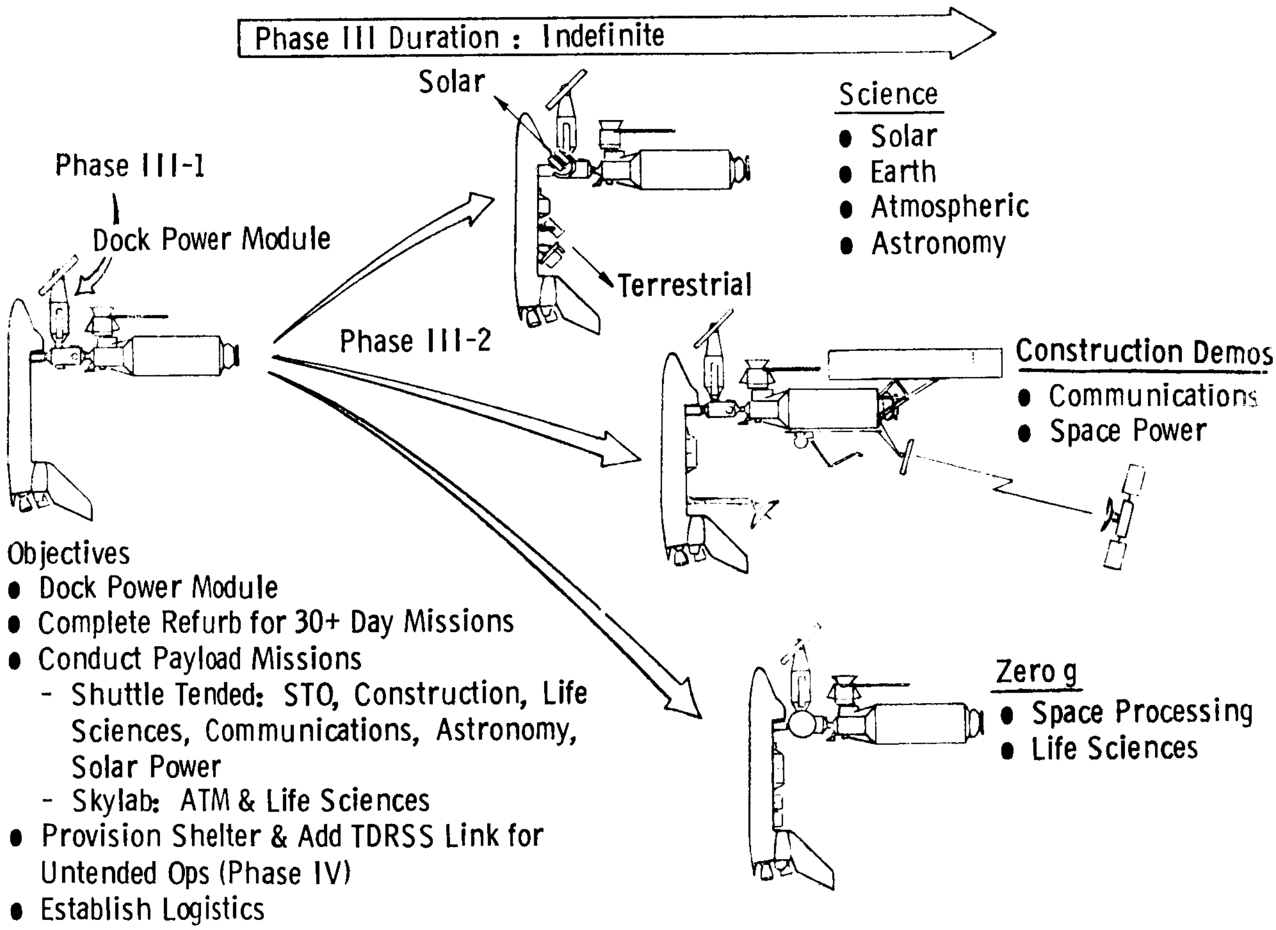


Figure 1-6 Phase III Activities and Objectives

communications through TDRSS to the ground are added, the Interface Module and other areas of the Cluster are provisioned to act as a shelter in case of major malfunction, and a logistics resupply system is implemented.

Phase IV is defined as untended operation (Shuttle unattached) with missions moving toward continuous manning and growth payloads (Figure 1-7). The Orbiter delivers payload and logistics resupply. For costing purposes, we have assumed Phase IV will start in 1986. However, the phase can begin when 1) autonomous TDRSS communications are added to Skylab, 2) Shelter/rescue provisions are available and 3) A logistics resupply system is available. Long duration payload operations can be performed and payloads can be stored on the cluster for periodic reuse. This can reduce the frequency of delivery to and from orbit, reducing transportation cost.

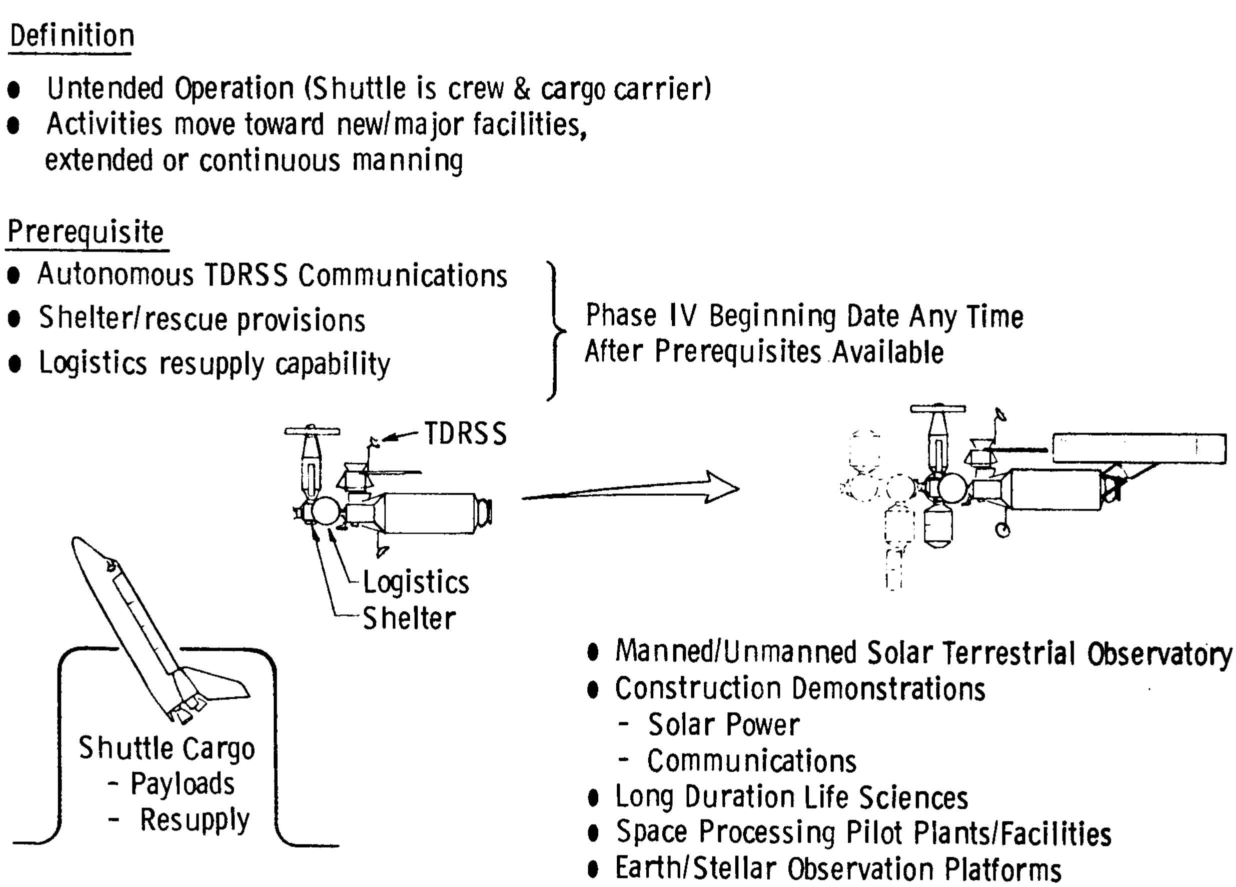


Figure 1-7 Phase IV Program

The Interface Module provides docking and interface services among Skylab, Power Module, Shuttle, a resupply module, and docked or berthed payloads. Figure 1-8 shows the Cluster prior to docking of the Power Module in early 1984. We assessed earlier utilization of Skylab prior to the Power Module (with stabilization) being docked, which resulted in an Interface Module option.

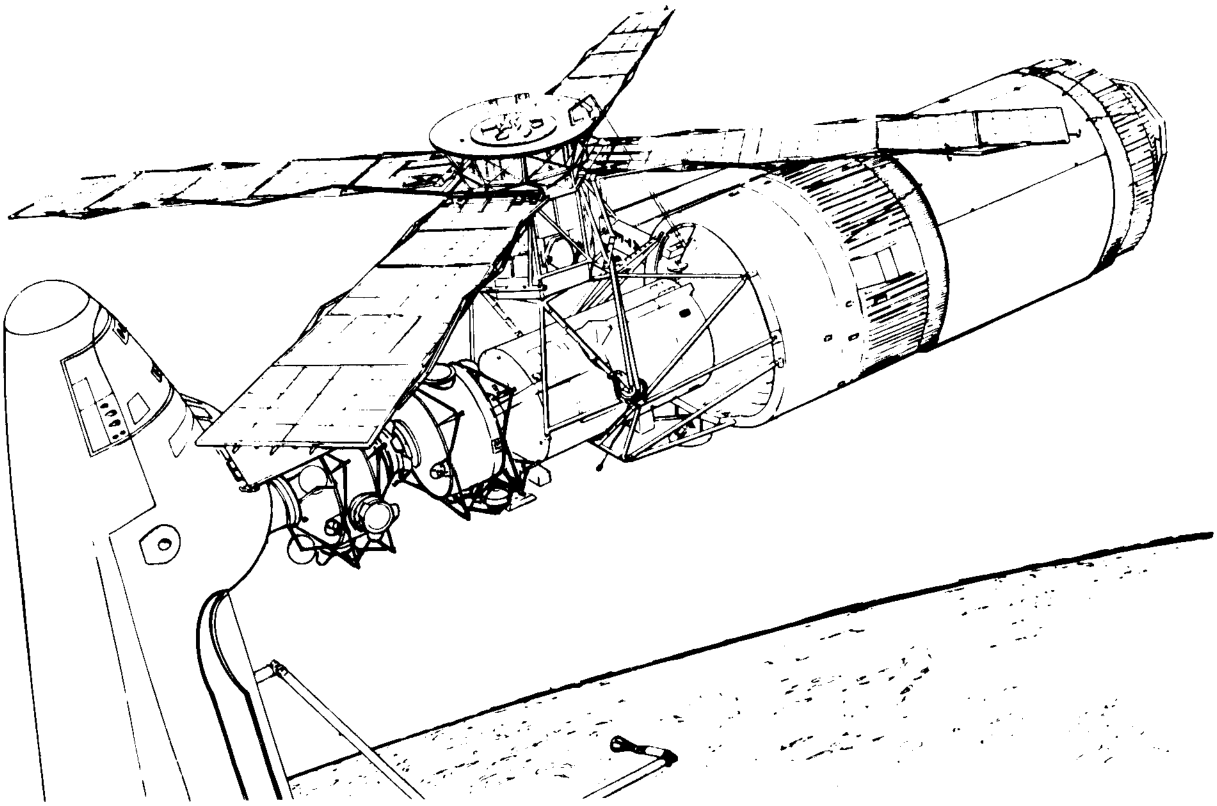


Figure 1-8 Skylab Reuse--Interface Module Option with Stabilization

This Interface Module option with stabilization (CMGs) provides some early Skylab operations in 1982, rather than 1984 with Power Module, frees the Power Module for other activities after 1984, and stabilizes Skylab for docking of an additional refurbishment flight and docking of the Power Module in 1984. Three CMGs are mounted on the module providing stability during Shuttle docking and refurbishment operations and, when supplemented by the Orbiter Vernier Control System, will allow some maneuvering. But, full cluster operation requires 6 CMGs (considering one to be a spare). The Interface Module can therefore supplement the Power Module, (with 3 CMGs for this option) which is used with Skylab in 1984. The Interface Module is attached to Skylab using either the Remote Manipulator System Arm or the Teleoperator Retrieval System (TRS). Another optional feature shown is the mounting of O_2 and N_2 tanks as external stores. We recommend that the TACS be at least partially refilled with N_2 on the first refurbishment mission to provide stability for the next mission. This eliminates the need to use the Teleoperator Retrieval System to stabilize Skylab after the first flight.

Phase III options, as established by NASA, were devised (Figure 1-9) to understand the programmatic and cost impacts of the initial Skylab reuse operations (Orbiter tended), with the use of the Power Module. The options encompass habitability only (with cargo bay experiments), selected Skylab experiments, and add-on payloads. Option A operates payloads from the Orbiter Cargo Bay, with Skylab providing habitability. Option B includes cargo bay payloads plus selected Skylab experiments. Option C adds payloads to the Cluster by docking them to the Interface Module.

OPTIONS	APPROACH
A. **Habitability Only** • No Skylab Experiments Activated • Cargo Bay Experiments Only	Define reactivation requirements/ concepts to bring Skylab back to 3-man crew capability. Define benefits and limitations of Skylab/Orbiter/Power Module cluster for currently planned missions.
B. Selected Skylab Experiments Option A Plus: B1 - Selected OWS/MDA Experiments B2 - Selected MDA/ATM Experiments B3 - All of Above C. Add-Ons Option B3 Plus: • New Docked/Berthed Experiments (Spacelab • Operate Only in Shuttle Tended Mode	Derive representative payloads for each discipline. Define detailed requirements for representative payloads. Derive Skylab/Orbiter/Power Module capabilities after activation - Power/Pointing (incl. limitations)/ ECS/TCS Define benefits of Skylab for each discipline.

Figure 1-9 Phase III Options

Representative payloads for Skylab reuse were identified and requirements defined. These requirements, after coordination with responsible MSFC groups, were used to define payload accommodations. Early payloads (1984-1986) were emphasized and later payloads in each discipline were defined to show growth trends. Responsibility for defining payloads and requirements was divided between the two contractors as shown in Figure 1-10. Payload requirements were applied to three Phase III options defined by MSFC.

	Requirements Defined By:
1. Solar and Terrestrial Physics A. Solar 1) ATM Reuse 2) Other Instruments B. Atmospheric/Magnetospheric 2. Solar Terrestrial Observatory (STO) 3. Astrophysics/Astronomy 4. Earth Viewing/Resources 5. Communication Programs	Martin Marietta
6. Space Processing A. Skylab B. Other 7. Life Sciences A. Skylab Biomedical B. Other 8. Solar Power System Development	McDonnell Douglas

Figure 1-10 Payload Discipline Areas

There are many significant reasons for the reuse of Skylab. A summary of major reasons is presented in Figure 1-11.

The Skylab Program was conceived and defined in the late 1960s for three operational flights in 1973 and 1974. At that time the Saturn V was available as a launch vehicle,having been developed for the Apollo manned mission to the moon. The Skylab Program made extensive use of Apollo developments including the large S-IV stage modified to be a manned laboratory. This Orbital Workshop (OWS) together with the MDA and AM gave the crew habitable (free) volume of 12,400 ft^3. This was more than ample for the 1973 mission needs, and now offers a potential for evolutionary expansion from three to seven crew and IVA installation and operation of experiments.

Because the Saturn Program has terminated, only the STS is now available to launch payloads up to 65,000 lbs. To orbit a platform the weight of Skylab would require 4 to 5 shuttle flights costing over $100 million alone. This does not include costs of extensive on-orbit assembly and checkout operations.

Other significant items are tabulated on this chart that are results of Skylab reuse analyses during the past year by government, industry and independent scientists and engineers. Principal investigators (PIs) have expressed their support for Skylab reuse for extended duration experiments to complement those experiments now being planned for Spacelab and other space programs.

- Space Platform Exists in Orbit (hundreds-of-millions-of-dollars resource)
    - 12,400 ft^3: can expand crews (6-7) and payload capabilities
- Saturn V No Longer Available To Launch Equivalent Size Platform
    - Requires 4 - 5 Shuttle flights with smaller diameter platform
- Provides Extended Habitation Capability For Early Shuttle/Spacelab Operations
- Provides Early Free-Flyer Spacelab When Docked To Skylab
- Supports Long Duration Operations
    - Evaluation of Skylab materials and equipment
    - Payloads/experiments requiring extensive on-orbit time
- Frees Orbiter For Other Uses
- Accommodates Most Payloads Identified During Next Decade
    - Experiments (70 to 80% of Spacelab Mission Model payloads)
    - Demonstration units
- Provides Early Capability For STO & Space Construction R&T With Man-In-Loop
- Develops Maintenance Techniques (EVA & IVA) To Support Other Programs
    - Transfer of fuels, gases, fluids, etc.
    - Parts replacement, repair, general maintenance
- Reduces/Eliminates Long Duration Orbiter Kits

Figure 1-11 Skylab is Our Space Platform!--Why?

2.0 UTILIZATION REQUIREMENTS AND MISSION ACCOMMODATIONS

This chapter presents a summary of results of our studies of requirements placed on Skylab reuse and the capability of Skylab to accommodate those requirements. The analyses of requirements included both habitation/payload and science/technology. Both of these were supported by previous Skylab experience and lessons learned during extended manned on-orbit operations.

2.1 HABITABILITY

2.1.1 BACKGROUND

Skylab represented the first opportunity to systematically evaluate habitability issues since it was the first space vehicle designed to enhance rather than compromise habitability. Skylab was not an orderly extension or evolution of Mercury, Gemini, and Apollo spacecraft designs, but represented an entirely new approach in manned space systems. For example, compared to Apollo, the mission length (84 days, SL-4) showed a 600 percent increase; volume (12,000 ft^3), a 4000 percent increase; man/machine interfaces, 3000 different controls and displays, a 250 percent increase; and 3000 stowed items, a 400 percent increase. More importantly, Skylab was the first system with dedicated crew quarters designed for different living and working functions. The food and water system, personal hygiene system, restraint and mobility aids, and sleeping accommodations were new.

Skylab experiment M487, "Habitability/Crew Quarters," was developed as an evaluation study of habitability accommodations on the Skylab elements (MDA, AM, and OWS). The results of the experiment provided a basis for establishing habitability requirements for long-term living and working in zero-g. For the purposes of experiment M487, habitability was evaluated in terms of the following nine elements:

1) Environment - thermal comfort, airflow, humidity, noise, illumination.

2) Architecture - crew compartments, work areas, traffic areas, stowage, decor.

3) Mobility aids and restraints.

4) Food and water.

5) Personal Hygiene - waste management, common-use equipment, individual-use provisions.

6) Housekeeping.

7) Communications.

8) Garments.

9) Off-duty activities.

The basic conclusion of the experiment was that Skylab provided a highly satisfactory living environment for three-man crews. Certain problem areas were identified, but Skylab habitability designs and provisions were well-received. It was concluded that one-g habitability designs and accommodations can be readily adapted to zero-g environments. The one exception to this conclusion concerns designs and provisions for personal hygiene which should be improved and adapted for both sexes.

Skylab experiment M516, "Crew Activities/Maintenance," was developed as an evaluation study of human performance capabilities in zero-g. The results of the experiment have obvious relevance for habitability, since the data provide a basis for understanding and recommending means of effectively utilizing human performance capabilities in manned space systems. Skylab represented the first opportunity to systematically evaluate a broad spectrum of human performance capabilities, as it was the first manned space system in which the crew performed numerous earth-like work activities in zero-g. The major areas of concern for M516 were as follows:

1) Manual dexterity - manual work, performance adaptation.

2) Locomotion.

3) Logistics Management - transporting equipment, managing items at work sites.

4) Maintenance - activities, work sites, equipment provisions, fasteners and electrical connectors.

5) Crew Activities - Use of men in space, experiment and operational activities, personal time scheduling, training effectiveness, controls, and displays.

A major conclusion is man can live and work efficiently in zero-g for periods as long as three months and, by extrapolation of medical data, longer periods can be obtained. For example: A) given adequate foot restraints and tools, the crewman can perform any manual or maintenance task in zero-g that he can in one-g; B) man can easily handle and maneuver large mass items (in fact, the upper limit of this capability has not been established by Skylab experience); and, C) translating in zero-g is, in general, easier than translating in one-g.

To provide a perspective for discussions of habitability, four issues basic to understanding habitability need to be addressed. These four issues concern: 1) The definition of habitability; 2) Measurement of habitability; 3) Habitability criteria; 4) factors that affect habitability evaluations.

Definition

Habitability is difficult to define. It means different things to different people, and much of the confusion and disagreement arising during discussions of habitability can be traced to basic differences in definition. Therefore, to provide a common basis for use of the term "habitability", we will define it as, "all issues (physical, physiological, psychological, and social) relating to the living environment which bear on the comfort, happiness, motivation, and effectiveness of occupants."

Measurement

Given the subjective and complex nature of habitability, measurement is rather difficult. Habitability measurement involves relationships between physical dimensions/accommodations of the environment and psychological responses to physical dimensions. Given a specific physical dimension or accommodation, values can be related to various psychological dimensions, for example:

Discomfort	psychological reaction	Comfort
Degraded	performance effectiveness	Optimal
Low	Morale	High

The problem in establishing required relationships is that while the physical dimensions can be objectively and reliably measured, the psychological dimensions must be subjectively measured, resulting in considerable data variance.

Criteria

Numerous attempts have been made to establish sets of specific, definitive habitability criteria. In terms of basic life support, habitability criteria can be set with considerable confidence. However, when we depart from basic life support, there is much less agreement and no single source or ultimate set of criteria exists for either the one-g or zero-g environments. One reason for this situation is that habitability criteria vary as a function of the measure used to determine habitability adequacy. For example, there will usually be a major difference between criteria established by asking people what they prefer and criteria established on the basis of preventing performance degradation. A related point is that habitability criteria, however determined, must be developed empirically - by having people evaluate habitability dimensions during occupancy in a given environmental situation. Often, there is a very distinct difference between what people think will be important and what actually turns out to be important in an isolated environment.

Factors Affecting Habitability Evaluation

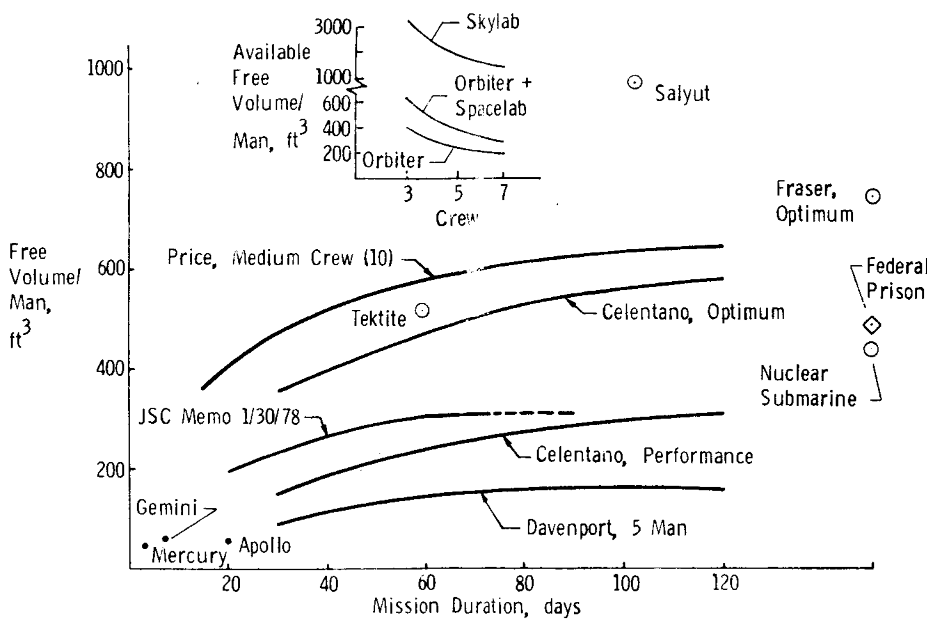
As previously mentioned, habitability is highly subjective, and considerable variance exists in data obtained during habitability assessment studies. Much of this variance is attributable to the fact that no two humans are identical. The assessment of habitability will vary as a function of four major factors: 1) crew size; 2) crew composition; 3) mission duration; and 4) individual differences.

2.1.2 HABITABILITY LESSONS LEARNED

Data collected for Skylab experiments M487 and M516 indicated that Skylab vehicles, in general, provided a highly satisfactory living and working environment for crews. Areas where habitability improvements were desirable were noted, but the habitability designs and accommodations of Skylab in no way compromised the performance effectiveness of crew members. Indeed, many aspects were evaluated as highly desirable for future programs. In terms of individual differences in habitability evaluations, agreement among the Skylab crewmen was much more common than disagreement. However, there were examples of differences among individual crewmen and differences among crews in habitability evaluations.

Many habitability lessons were learned that are relevant for Skylab reuse. Habitability aspects on SL were the same as would occur in any other isolated environment. The crew needs a way to attain a modicum of privacy, diversions from operational routine, exercise, recreation and personal preferences in varying surroundings. The highest priority items in the daily schedule were meals, personal hygiene, exercise, sleep, and off-duty time. Skylab was the first manned space program to demonstrate the significance of individual differences and mission duration in habitability assessments. Food variety, quality, and availability of snacks are very important. A shower facility is highly desirable for personal cleanliness, and the importance of factors affecting habitability evaluation increased as mission duration increased.

Required crew volumes have been defined by a number of sources (Figure 2.1-1). It appears that minimum volumes per man are



Volume criteria considerably less than Skylab (3300 ft^3/man.)

Figure 2.1-1 Extended Missions - Habitability Volume Criteria about 150 ft^3, with somewhat larger volumes (300-to-600 ft^3 per man) defined, at which crew performance improves. Free volumes available in the Shuttle, Shuttle plus Spacelab, and Skylab far exceed the requirement, providing 1) the ability to obtain more privacy; 2) "get away" from other crew members; 3) space to move in experiments; and, 4) volume to expand the crew size.

Figure 2.1-2 shows a mockup of the Skylab crew area. The crew sleeping compartment is shown on the left with privacy curtains opened. The waste management compartment is shown in the center and the wardroom on the right contains refrigerator and freezers. Food preparation table, and food and supplies located in standard lockers. The trash airlock is in the center of the floor, and the swing chair, lower body negative pressure unit, ergometer and whole body shoulder are located around the equipment compartment. The control panel is on the OWS wall.

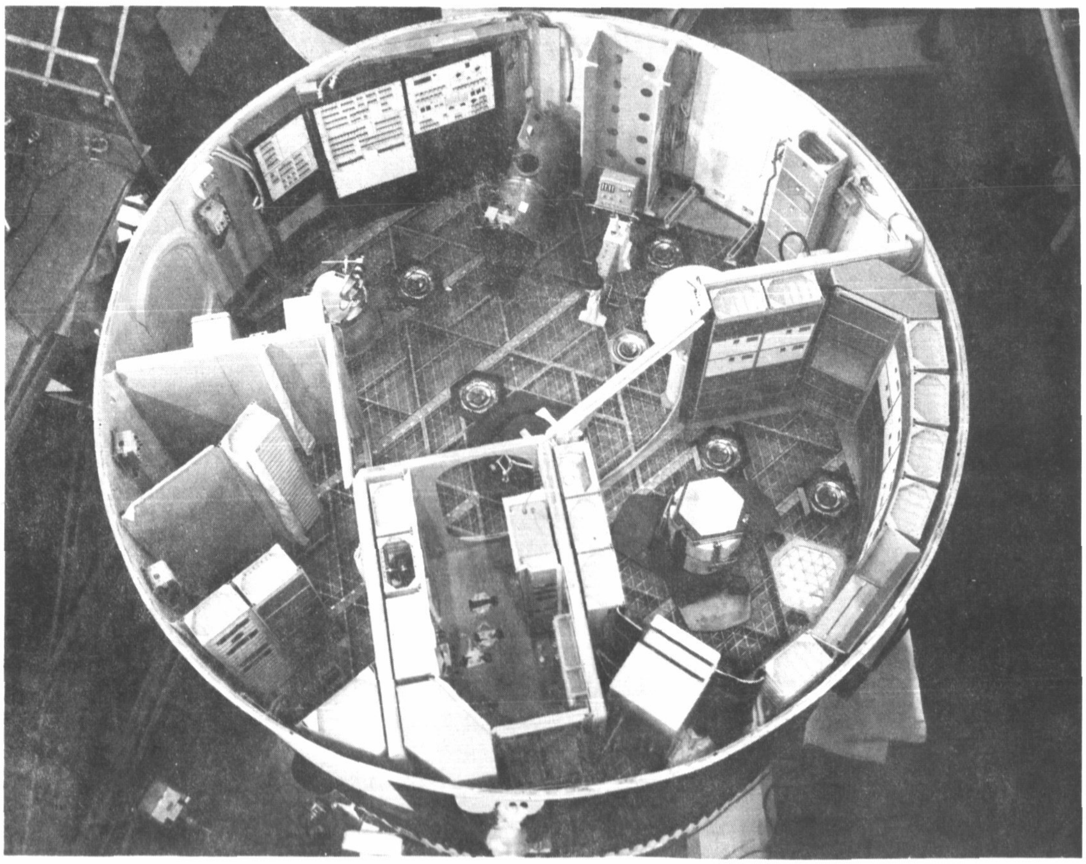


Figure 2.1-2 Skylab Crew Area

2.1.3 EXISTING SKYLAB AND SHUTTLE HABITABILITY CAPABILITY

Skylab capabilities are shown in Figure 2.1-3. Some of them are unique when compared with other alternatives (Orbiter and Spacelab). First, approximately 10,000 ft^3 of volume is available in the OWS alone which can provide "get away" areas and exercise/recreation. Refrigerated and frozen foods can be provided, increasing the variety of food available. The shower, although it could be improved, was felt by most Skylab crewmen as a definite benefit. Sleep quarters are private and separated from other areas. The bicycle ergometer, tension device, and free choice exercise such as hand ball and running around the water tank area provided needed breaks from the work day. Running is also found desirable among nuclear submarine crewmen. Although volumes per man in submarine crew quarters aren't large, the crew obtains exercise and a break from routine by running around the missile tubes.

VOLUME

- Total 283 m^3 (10,000 ft^3)
- Crew Quarters 67.2 m^3 (2375 ft^3)

Rest/Recreation

- Three Private Sleep Quarters
- Acoustics: 50 to 60 dB
- Open Floor Space Approx 27 m^3 (290 ft^2) for Additional Equipment/Quarters

Food Preparation/Stowage

- Refrigerated/Frozen Food Storage
- Potable Water 178 Man-Days Now; 595-691 Man-Days Full
- Food Lockers & Freezers: 420 Man-Days
- Food Galley - Hot & Cold Food Preparation

Exercise/Physical Well Being

- Bicycle Ergometer
- Lower Body Neg. Pressure
- Mass Measurement

Hygiene

- Shower
- Waste Management: 3 Male; Can Adapt for Female
- Hand Washer
- Trash Airlock: 1/3 Full, 1,089 Man-Days Until Full (Approximately 12 30-Day, 3-Man Missions)
- Water: 149-475 Man-Days Now; 654-980 Man-Days Full

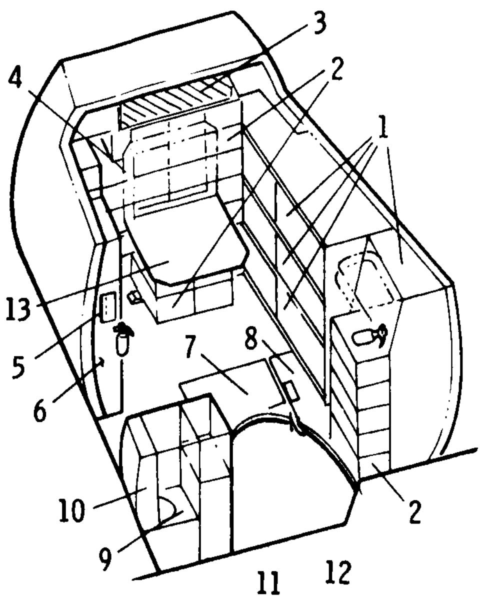
Environment

- Existing System: 23°C (74°F)
- Noise 50 to 60 dB
- Humidity 60 to 70%
- CO_2 & H_2O Controlled, Removed
- 5 psi (3.6 psi O_2)
- O_2/N_2 157 Man-Days Now; 664 Man-Days Full; 250 Man-Days/Tank
- Shelter: Orbiter & Skylab ECLS Separate
- EVA via Skylab - No Prebreathe

Figure 2.1-3 Existing Skylab Habitability Capability

Orbiter provisions are shown for comparison in Figure 2.1-4. A volume of about 300 ft^3 per man (based on a four man crew) is available, although privacy is restricted and sleep stations are in working areas. Addition of a Spacelab in the cargo bay increases the volume per man as shown previously in (Figure 2.1-1).

Middeck Sleep/Galley/
Dining/Work Station



1 Sleep Station (Up to 4)
2 Modular Stowage } 2.1 m^3 (73 ft^3)
3 Soft Stowage
4 Dining/Work Table (Stowed)
5 Personal Hygiene Station (Hand Washer)
6 Galley (37 ft^3)
7 LiOH Stowage
8 Wet Trash Stowage
9 Waste Management System (Male/Female)
10 Hygiene Stowage
11 Stowage
12 Avionics
13 Dining/Work Table

Habitable Volume:
- Airlock in 30 m^3 (1082 ft^3) Both Decks
- Airlock out 35.7 m^3 (1226 ft^3)

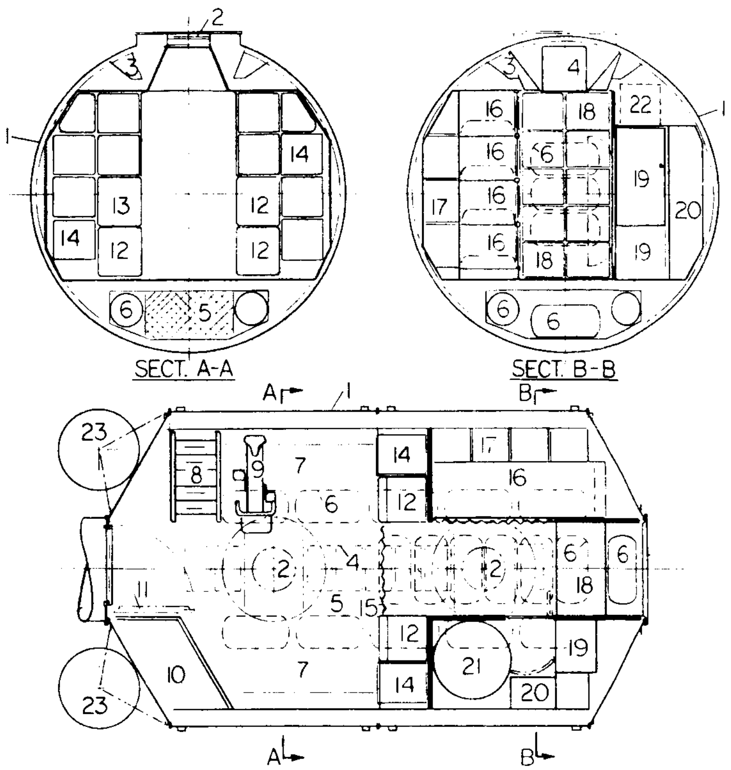
Operating Pressure: 14.7 psi (3.2 psi pp O_2)

Emergency Pressure: 8.0 psi (2.6 psi pp O_2)

Crew Systems: 4 to 7 Passengers, 28 Man Days + 16 Man Day Contingency

Figure 2.1-4 Operational Orbiter

A representative crew module configuration is shown in Figure 2.1-5. as it might be built into the Shuttle cargo bay. Free volumes increase from 300 ft^3/man to about 600 ft^3/man. Private sleep quarters and hygiene areas are provided, plus a recreation area. Galley provisions are assumed in the orbiter, with food storage -- including frozen items provided in the module. The equivalent of two Spacelab segments are required.



1. Pressure Shell Spacelab
2. Viewports (2) Spacelab
3. Support Structure Spacelab
4. Stow Containers (8)
5. ECLS & Other Systems
6. Water Tanks (19) Shuttle
7. Exercise/Recreation Area
8. Treadmill
9. Ergometer
10. Entertainment Center
11. Im Dia. Pressure Hatch
12. Freezer (3)
13. Refrigerator (1)
14. Ambient Food Lockers (12)
15. Privacy
16. Sleeping Quarters (4) Shuttle
17. Personal Lockers
18. Crew Supplies Lockers (10)
19. Waste Management Compt.
20. Personal Hygiene Unit
21. Shower
22. Stow Container, Hygiene Supplies
23. Gas Tanks (Skylab N_2 Tanks)

Figure 2.1-5 Shuttle Cargo Bay Crew Module

The Space Shuttle requires kits, consumables and, beyond some mission duration, a crew module in the payload bay for flying extended duration missions. The weight of these items is indicated in the lower cross-hatched area (Figure 2.1-6) as a function of mission duration. Data were taken directly from a Rockwell Study, (Orbiter Kits For Operation With Space Power Modules, 11/3/77). Equipment and consumables are added in the Orbiter cabin and in the forward end of the cargo bay. At about 40-42 days, a short Spacelab crew sleep module is added. At 60 days, half to two-thirds of the allowable return weight is required for mission extension. The upper cross hatched area shows the envelope of several representative payloads defined during this study. These are primarily Spacelab type payloads which are returned to earth after each mission. Addition of the payload reduces the duration limit (or conversely,

- Shuttle requires kits, consumables, and crew module for long duration missions.
- Kits, consumables, and crew module use significant part of payload capability
- Addition of payload reduces duration capability.
- Long duration Shuttle requires more flights for equivalent science than use of Skylab.
- Skylab duration unconstrained (with resupply).

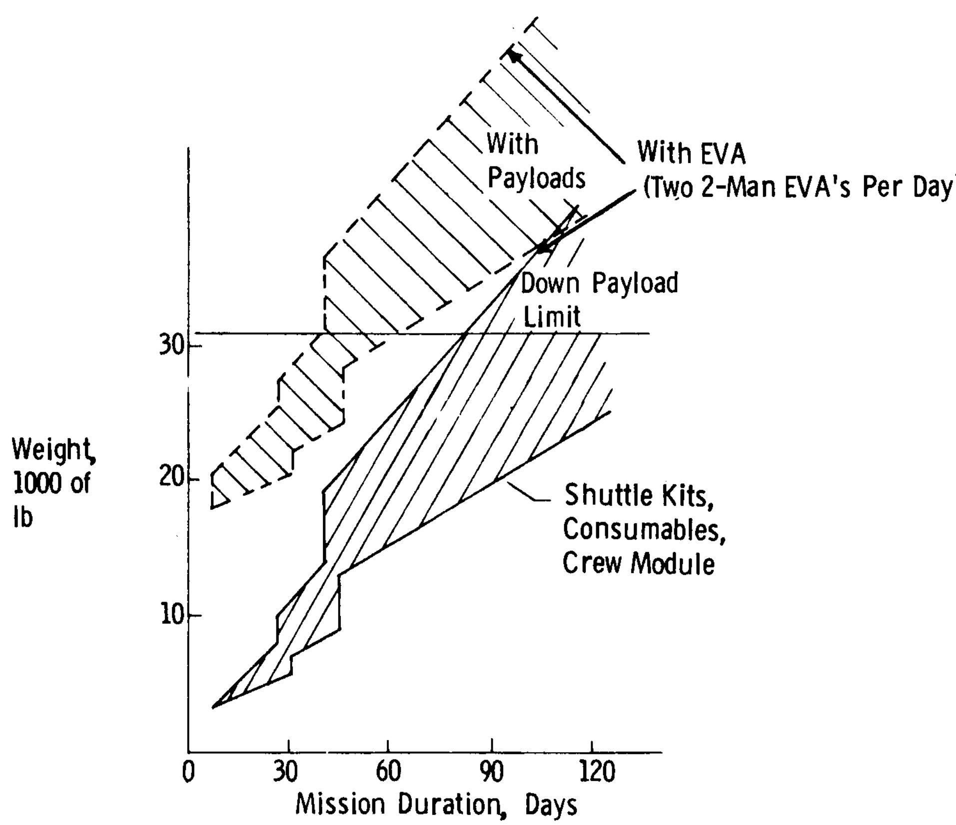


Figure 2.1-6 Comparison of Long Duration Missions, Shuttle/Spacelab and Skylab

addition of the crew module and consumables reduce the allowable payload). To obtain equivalent science or other applications, additional Shuttle flights will be required due to this payload reduction.

Equivalent Science is defined as the same number of man days in orbit for either the Orbiter or Skylab. The transportation comparisons shown in Figure 2.1-7 assume half of the payload bay weight and volume used for crew module and consumables. Skylab requires part of one flight for resupply plus later delivery of a full cargo bay payload complement.

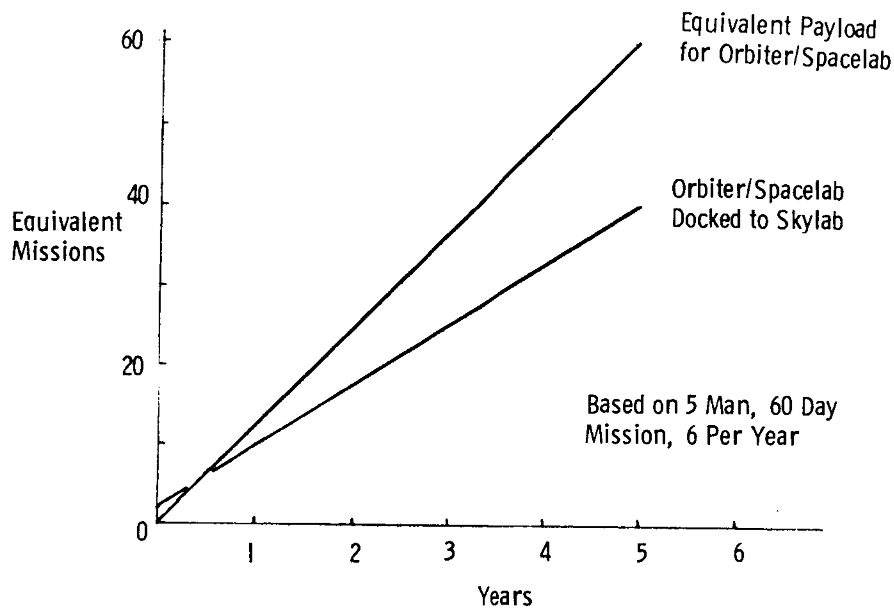


Figure 2.1-7 Transportation Comparisons - Orbiter/Spacelab Crew Module and Skylab

For tended mode payloads configured with both the Orbiter and Skylab, prebreathing may be required prior to entering Skylab from the Orbiter. Prebreathing considerations are summarized on Figure 2.1-8. Several criteria must be met to avoid prebreathing. 1) The Orbiter pressure must be no more than twice that of Skylab; 2) The Shuttle flammability limit (25% O_2) must be observed; and 3) Proper oxygen partial pressures (above 2.5 psi) must be provided to the crew for biomedical reasons.

Three alternatives are shown on the figure. The first one makes no changes to either Orbiter or Skylab cabin pressures, but requires approximately two hours of prebreathing to go from Orbiter to Skylab initially, or after an extended stay in the Orbiter. For short visits to the Orbiter prebreathing time reduces to several minutes. The system is workable, but operationally undesirable. As a second alternative, the Orbiter pressure is dropped to 12.6 psi and Skylab increased to 6.3 psi.

These pressures represent the point at which all three criteria are satisfied. Orbiter and Skylab modifications are not extensive. The third alternative requires no change to the Orbiter. Skylab pressure is increased to 7.3 psi (Skylab pressure capability is 7.5 psi assuming a continued requirement for a safety factor of 3.0 on windows). Skylab changes are similar to the second alternative, i.e., shutoff of the three relief valves, installation of higher pressure relief valves, and either manual control or changeout of Skylab pressure regulators.

Key Issues

- Prebreathing (Ratio of Orbiter Pressure to Skylab Pressure)
- Flammability
- Partial Pressure of O_2 for Crew

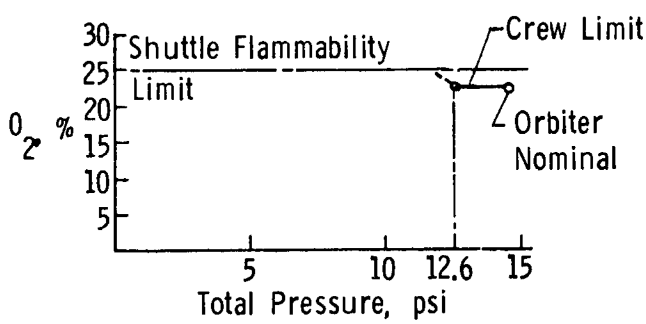


Figure 2.1-8 Prebreathing

Orbiter 14.7/Skylab 5

- Workable System
- Prebreathe Required
- No ECLS Mods

Orbiter 12.6/Skylab 6.3

- Orbiter & Skylab Mods Not Extensive
- No Prebreathe
- Consider for Use

Orbiter 14.7/Skylab 7.3

- No Orbiter Mods
- No Prebreathe
- Skylab Structure Limit 7.5 psia
- Skylab Mods Not Extensive
- Consider for Use

2.1.4 SUMMARY OF HABITABILITY BENEFITS OF SKYLAB

Benefits of using Skylab as a manned facility are summarized on the following table (2.1-1). Volumes are available which exceed performance volume criteria. In addition, Skylab provides privacy, the ability to divert from operational routines, exercise, and hygiene facilities which are not available in the operational Orbiter. Crews found these provisions of increasing importance with longer missions during the Skylab program.

When compared to using a Shuttle for long duration missions, Skylab can offer some advantages. Transportation costs can be reduced, especially in the Shuttle untended mode. In this mode, the Shuttle is used as a delivery vehicle. Long duration subsystems for the Orbiter, would not be required nor would the development of an extended durations crew module.

Table 2.1-1 Habitability Benefits

- Skylab crews found the following of increasing importance with longer missions:

- Attain privacy, divert from operational routine - Exercise/Recreate - Hygiene/Shower	Skylab volume & equipment provides these; orbiter habitability meets performance type criteria.

- Crew members should find Skylab less confining, restraining.
- Use of Skylab can reduce STS Transportation & Operations Costs
- Complementary Skylab operations can reduce Orbiter long duration kits (but won't eliminate all of them).

2.2 PAYLOADS

2.2.1 Background

The evolution of manned earth-orbiting science and technology programs is depicted in Figure 2.2-1, showing the interrelations between Skylab and Space Shuttle programs. As indicated, the evolution is leading toward national goals of improving our general well-being and living standards through useful earth orbit activities. Skylab is a national facility that can complement the Space Shuttle and other programs in reaching these goals.

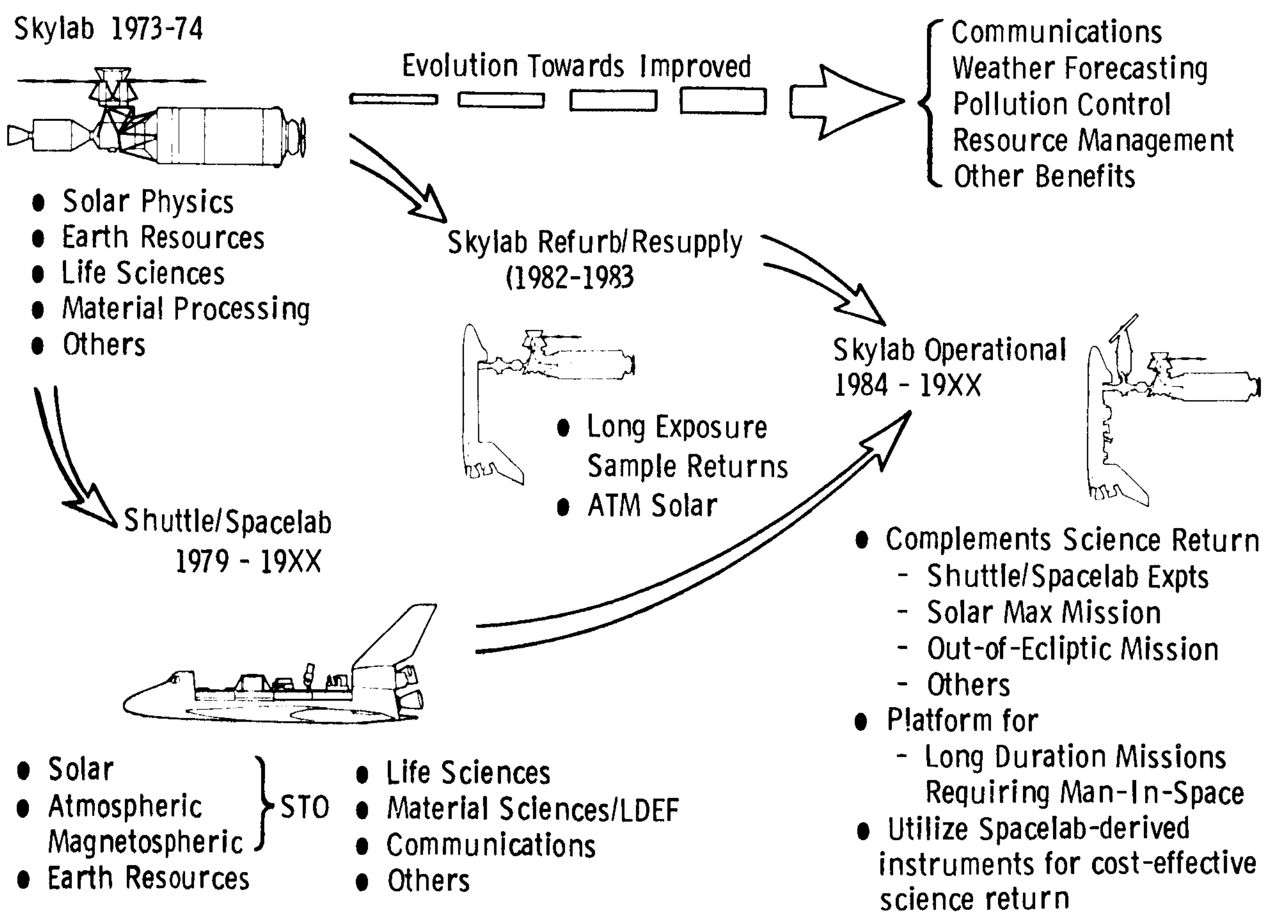


Figure 2.2-1 Science Program Evolution

The 1973-74 Skylab missions were major steps toward proving the utility of man and equipment in earth orbit for long durations. Many benefits resulted from that space program including demands for further man-in-space activities. A subsequent evolutionary step was a national commitment to the Shuttle/Spacelab programs. These will continue earth-orbiting experimentation on an international basis during the 1980's.

As Shuttle-related activities progressed, further need for man in space developed. Projections show the unique benefits of Skylab Reuse to complement the use of Shuttle and other experiment programs. With Skylab once again habitable, science and technology programs can evolve during the 1980-1990 period to provide data needed in meeting the demands forecast for improved services.

In the present study it is important to examine the forecasts of requirements for future payloads and to analyze how well Skylab could accommodate these requirements. Our approach in defining the payload benefits of Skylab Reuse is summarized in the upper flow diagram of Figure 2.2-2. Representative experiment payloads were defined with their detailed requirements for power, viewing, crew, etc. As discussed earlier, Martin Marietta and MDAC were each assigned specific areas for which to establish requirements. All the requirements were analyzed and compared with capabilities of the Skylab complex. The comparisons resulted in definitions of constraints and benefits of Skylab Reuse. The following discussions present the analysis techniques and results of these tasks. Considerable valuable assistance was provided by personnel at NASA/MSFC in defining representative payloads for Skylab Reuse and their requirements.

As indicated on Figure 2.2-2, typical payloads in each discipline area were forecast over the next decade. (A detailed presentation and discussion of requirements for orbiting experiments is given in "Experiment Requirements For Skylab Reuse," Martin Marietta Corporation TN-204803-78-901, 7 April 1978). Included were Skylab derivations, large growth payloads, and reuse of present Skylab experiment equipment. Specific pertinent data were tabulated for typical instruments and payload combinations related to discipline areas. Data included requirements for attitude pointing and stability, electrical power, thermal control, data rates, and crew functions. This figure illustrates a representative payload for carrying out solar terrestrial observations (STO) needed to understand the sun-earth interactions. The following section presents a summary of payload requirements for each of the discipline areas.

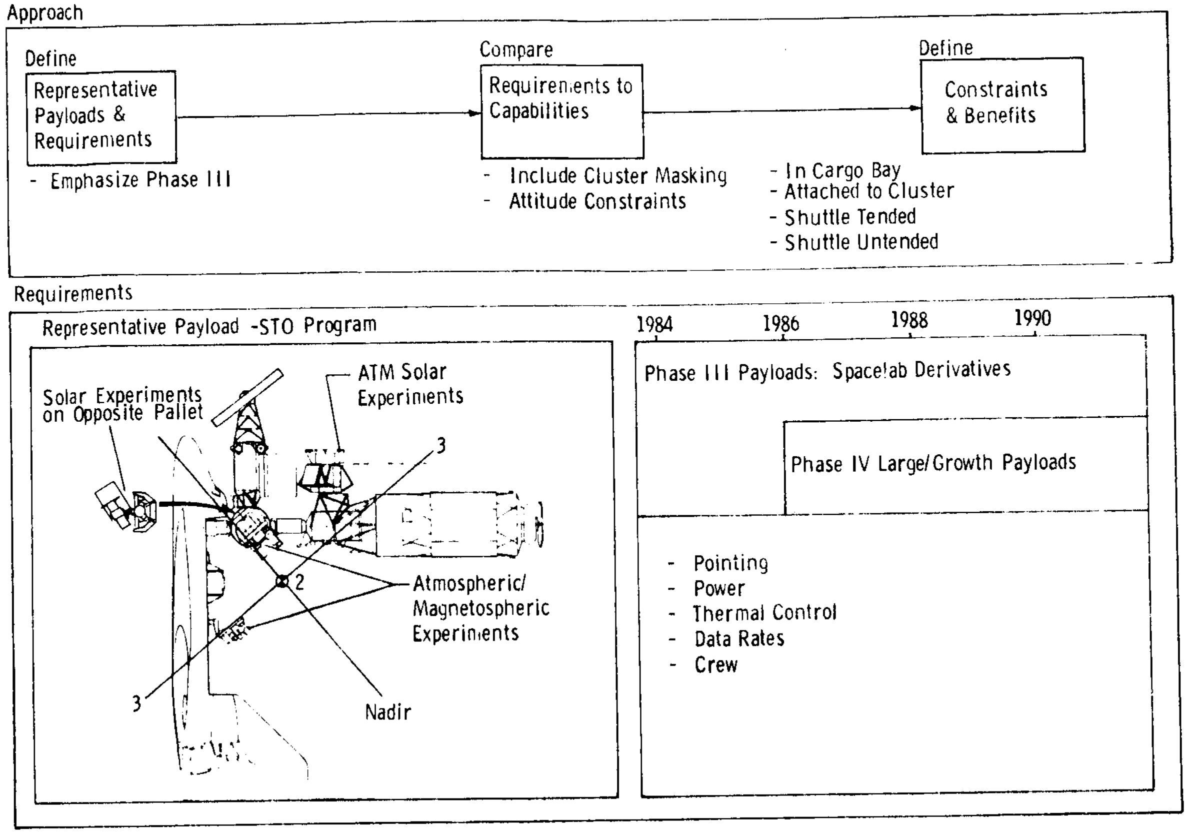


Figure 2.2-2 Payload Requirements Approach and Use in Study

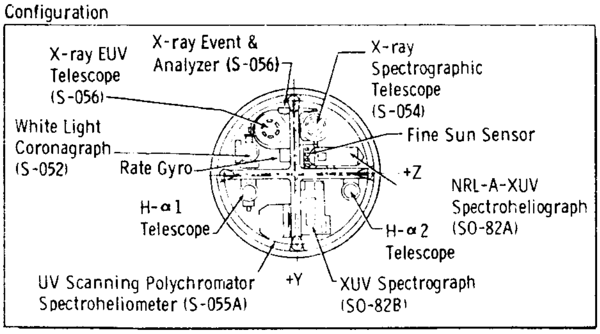
2.2.2 Payload Requirements

This section presents a summary of payload requirements for each of the various discipline areas included in this study. The status and requirements of the existing ATM instruments are presented because they can be reactivated to provide continuing utility in acquisition of solar data. Requirements of solar physics and the other discipline areas are then presented to illustrate requirements of representative payloads that were derived on the basis of analyses and data of many other studies including Spacelab Level A Sortie Payload Data, current NASA Description Sheets of payloads and NASA 5 year plan.

1) ATM Apollo Telescope Mount Requirements

The layout of the existing experiments on the Skylab ATM Canister is illustrated together with operating requirements, instrument and subsystem status summaries in Figure 2.2-3). All existing instruments and subsystems are judged to be operable and capable of providing very useful science data. The doors or door ramps of many instruments were pinned open during the Skylab missions to circumvent operating problems. The ATM instruments worked well with a few non-critical problems. These instruments have a high reuse value because of demonstrated performance capabilities including fine spatial and spectral resolutions. They support the data acquisition requirements of science in areas of solar physics and solar terrestrial observatory activities, and can complement the solar physics payloads being developed for use on the Shuttle/Spacelab. Data obtained with ATM instruments can also support the data of the planned solar maximum and solar polar missions.

Configuration



Operating Parameters	
Power	0.58 kW Instruments Operating
Pointing	Solar; ±2.5 arc-s Accuracy (EPC); 2.5 arc-s Stability for 15 minutes (EPC)
Thermal Control	Thermal Control Provided with Instruments
Data Rates	12 kbps; Compatible with Existing ATM
Crew	1 Crewman on C&D Console during Manned Observation Periods; EVA Film Replacement

Instrument and Subsystem Status			
Instrument	Instrument Status	Subsystem	Subsystem Status
White Light Coronagraph	Operable	Electrical	Adequate Power with/without Power Module
X-ray Spectrographic Telescope	Operable; Power On; Door Open	Command	ATM System Operable
UV Scanning Polychromator/Spectroheliometer	Operable; Door Ramp Latch Removed; Intermittent High Voltage	Communications	ATM System Operable
X-ray Telescope	Operable; Door Ramp Latch Removed; Several Minor Anomolies	Instrumentation	ATM System Operable
XUV Coronal Spectroheliograph	Operable; Frame Counter Out; Door Open	Thermal	Coolant Loops Pressurized
UV Spectrograph	Operable; Door Open	Pointing	Operable
H-α Telescope	Operable; Door Open		
Conclusion: End of mission data and recent interrogation tests show no inoperative instruments of subsystems. Full confirmation to be acquired by ground interrogations and revisits.			

Figure 2.2-3 ATM Reuse Requirements

Use of ATM instruments was limited during Skylab missions due to an EVA film replenishment requirement. This handicapped observational programs requiring rapid film usage. Observations of flares were also limited by the requirement that, after flare detection, rapid observations of the flare mode were initiated. These restrictions resulted in a shortage of preflare observations. In the planned Skylab/Power Module mode of operation, the instruments can be dedicated to high time resolution of short term transient events (continuous, high frequency observations). At this time in the cycle we could expect short-time - interval sequences of observations during preflare heating, flare beginning (trigger), and early rise phases.

Remote (or automatic) operation of the ATM instruments over a long time span would give an opportunity to study evolution of coronal structures above active regions, region interconnections, large loop systems, coronal holes, bright points, and the outer white light coronal features, such as helmet streamers. Reduced film usage in twice-per-day synoptic observations would permit observations for continuous periods of a year or more between film cassette replacement. This concept for remote ATM use requires study.

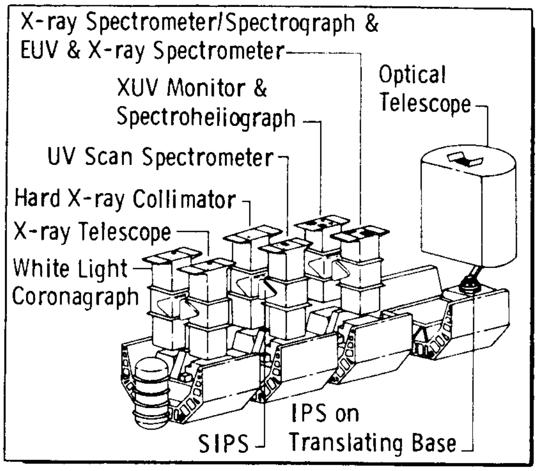
Observations of slowly evolving phenomena during various phases of the solar cycle will enable investigators to compare and contrast their evolutionary behavior with the time period of original Skylab flights, thus complementing these earlier data and improving resulting physical models of global sun variations.

2) Solar Physics Requirements

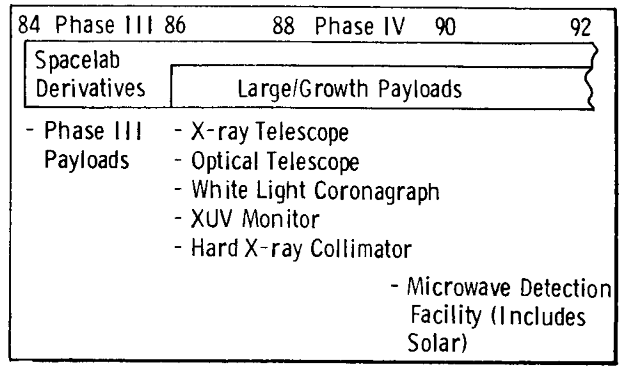
A typical solar physics payload, summary requirements, and growth payloads are illustrated in Figure 2.2-4. These instruments will provide data for studies of the sun, its mechanisms and fluctuations, origin of energy, solar wind, and the high energy acceleration processes in x-ray, ultraviolet and visible spectra. Stringent pointing requirements can be met by multiple instrument pointing mounts. Typical Phase III and IV growth payloads are listed through 1992.

In the solar physics area, desirable activities include defining the boundary conditions to the solar wind in the lower corona, confirming solar wind emissions from regions of open magnetic fields, evaluating energy deposition and magnetic field divergence, evaluating solar wind modulation processes, and evaluating terrestrial consequences to observed coronal variations.

Phase III Payload



Growth to Phase IV



Summary Requirements--Phase III Representative Payload

Pointing Control	Solar; 4 arc-s to $\pm$2 deg Accuracy; $\pm$0.2 arc-s to +0.5 deg Stability Narrow Fields-of-View
Power	1.0 kW Average (1.3 kW Peak) Instrument Operating Power
Thermal Control	Platform-Mounted Instruments Will Require Thermal Canisters for Control Necessary for Precise Pointing; 260 to 320 K Expected Operating Range
Data Rates	5 to 12 Mbps
Crew	2 Men for Each of 2 Shifts

Figure 2.2-4 Solar Physics Requirements

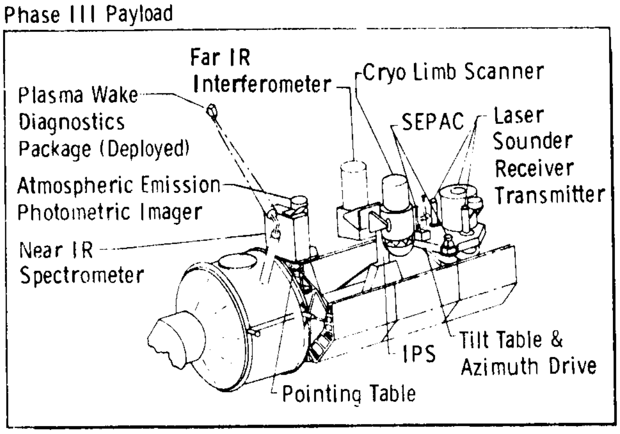
Studies of high energy acceleration processes on the sun include observing particle acceleration sites to define particle acceleration processes, observing outer corona for trapping of high energy particles and sites of energy dissipation, correlating acceleration processes with stressed solar magnetic fields to develop a predictive capability for impulsive events, and correlating impulsive events and energetic particle emissions with terrestrial effects. Another area, investigation of solar/stellar atmospheres, includes identifying modes of mechanical energy transport, evaluating the role of the nagnetic field in the structure of photosphere and chromosphere, identifying features which are sources of mass injection into the corona, and studying changes in magnitude and configuration of magnetic fields associated with types of solar activity.

The typical collection of solar instruments of Figure 2.2-4 addresses the above areas. These instruments are derived from a Spacelab solar physics complement and can be combined in a number of ways to meet weight/volume constraints and specific mission emphasis. All of the instruments are compatible and could be operated during the same mission. Although packaging constraints may not allow all of them to be placed in the Orbiter Bay simultaneously, they could be grouped in a free-flyer configuration while docked to Skylab.

3) Atmospheric/Magnetospheric Requirements

As part of the solar terrestrial observations, a typical atmospheric/magnetospheric payload is shown (Figure 2.2-5). Instruments shown are mounted on pointing platforms and on hinged deployable platform for clear field viewing. Other summary requirements are power, which is driven by the Laser Sounder and the

Phase III Payload



Growth to Phase IV

84 Phase III	86	88 Phase IV	90	92
Spacelab Derivatives	Large/Growth Payloads			

- Phase III Payloads
  - Cryogenic Limb Scanner
  - Laser Sounder
  - SEPAC
  - Diagnostic Package
  - Ejectable Plasma Diagnostic Package
  - Imaging Spectrometric Observatory

Summary Requirements--Phase III Representative Payload

Pointing Control	Earth Limb, Local Vertical, Magnetic Field Lines; ± 0.25 to ± 10 deg Accuracy; 0.36 to 3600 arc-s/s Stability
Power	3.7 to 5 kW Instrument Operating Power for Selected Experiments
Thermal Control	Platform-Mounted Instruments Will Require Thermal Canisters; Limb Scanner Contains LN_2 or LHe for Detector and Electron Accelerator; 270 to 330 K Expected Operating Range
Data Rates	6.3 Mbps
Crew	2 Men for Each of 2 Shifts

Figure 2.2-5 Atmospheric/Magnetospheric Physics Requirements

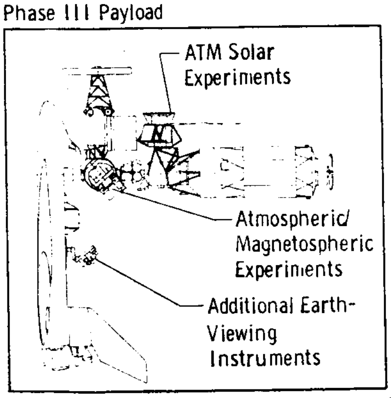
SEPAC experiments. Growth versions of payloads include cooperative two-body experiments requiring accurate positioning and communication with subsatellites for both magnetospheric and atmospheric studies.

The instruments shown in Figure 2.2-5 are derived from several Spacelab payloads, including Atmospheric, Magnetospheric, and Plasmas-in-Space Program; Ejectable Plasma Diagnostics Package; Atmospheric Emission Photometric Imaging; and Space Experiment with Particle Accelerators. A combined payload is shown which includes all of these instruments. Packaging constraints for the Orbiter Bay may limit the combination when operating with the experiments in the bay. However, all of the instruments could be included when operating in a free-flyer configuration docked to the Skylab.

4) Solar Terrestrial Observatory Requirements

Another significant payload planned for Phase III of the Skylab Reuse Program that also requires accurate pointing is the Solar Terrestrial Observatory, illustrated in Figure 2.2-6. As shown in the summary requirements, the pointing to the various targets

Phase III Payload



84 Phase III 86 88 Phase IV 90 92

Spacelab Derivatives	Large/Growth Payloads

- ATM Reuse
- Solar
- Atmospheric
- Magnetospheric
- Atmospheric Lidar
- Pinhole Camera

Uses Combinations of Instruments from Solar, Terrestrial, & Earth-Viewing Areas

Summary Requirements--Phase III Representative Payload	
Pointing Control	Solar, Earth Limb, Nadir--Simultaneous Viewing of Sun & Earth To Observe Short-Term Interactions
Power	5-kW Instrument Operating Power for Selected Instruments
Thermal Control	Thermal Canisters Required; 270 to 325 K Expected Operating Range
Data Rate	12 Mbps
Crew	2 Men for Each of 2 Shifts

Figure 2.2-6 Solar Terrestrial Observatory Requirements

(solar, earth limb, and nadir) are at times performed simultaneously to determine short-time interactions with the earth's atmosphere created by solar/solar wind phenomena. Growth versions of these payloads are planned for long duration to improve analytical models of the solar/terrestrial interactions.

The Solar Terrestrial Observatory (STO) represents the instruments providing data to scientific disciplines studying cause and effect between sun and earth. The studies of the many interactions require simultaneous, long duration observations which provide data on sequences of correlated events, such as: Sun, solar wind, magnetosphere, atmosphere. These studies have important practical use including ability to predict earth environments, long-lead forecasting and communication systems performance.

Highly coordinated observations, long and short term, are needed in several areas. For example in the solar area, continuous monitoring of full-disk solar flux over a wide electromagnetic spectrum is required using both broad band and emission line irradiance detectors. These observations complement and support those of related solar programs, such as the Solar Maximum Mission, the Solar Polar Mission, and the Pinhole Satellite.

In the magnetospheric area, measurements involve imaging of dynamic developments of major features, such as, 1) auroral oval, plasma sphere, and magnetopause, 2) active injection of waves, ionized gases and particles to simulate physical processes, and 3) passive plasma observations of plasma and wave characteristics as a measure of response to solar changes and as a guide for conduct of active experiments. In the atmospheric area, imaging is required to obtain data on characteristics of natural emissions on a global scale such as airglow and aurora. Limb scanning observations are needed to determine altitude variations of atmospheric composition and temperature. Active stimulations of emissions from atmospheric species using laser systems would provide data on density and temperature of the species.

Figure 2.2-7 emphasizes the changing nature of the sun and its influence on the earth. The large fluctuations of daily sunspot numbers show the rapid changes which occur on the sun. Flares erupt in seconds while prominances and corona persist for days. Sunspot groups can be detected for months and granularity fluctuates continually. Solar emission of particles and rays change

Sun Activity Is Intense:

- Continually Changing
- Random & Instantaneous Events
- Predominant 11-Year Cycle

Earth Response Is Global:

- Magnetosphere Perturbed
- Intense Aurora
- Communication Disrupted
- Ozone Degraded
- Storms Develop
- Icecap Melts or Expands

Strong Need for STO Manned Continuous Operations Expressed by MSFC:

- For Adequate Monitoring of Sun/Earth Interactions
- To Acquire Data at Time of Random Events and Later
- To Identify Correlations Among Sun and Earth Events
- To Improve Understanding and Analytic Modeling

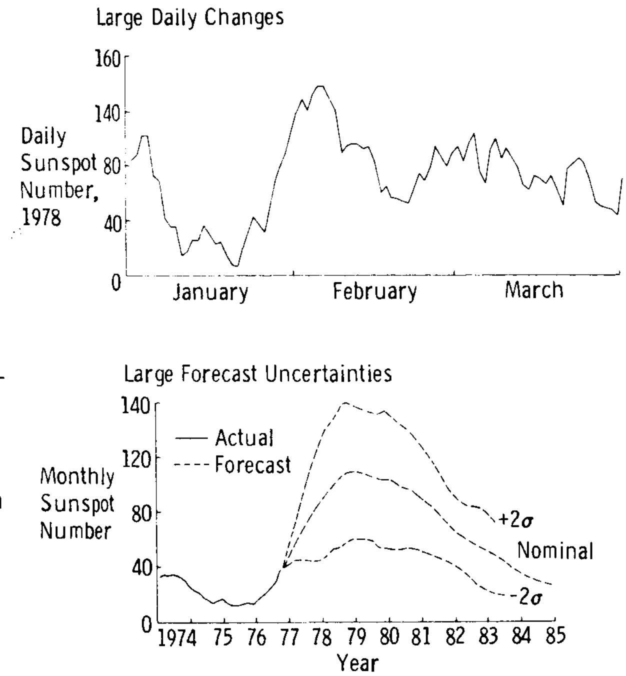


Figure 2.2-7 STO Needs Long Duration Flights

intensity as major phenomena wax and wane. The earth, submerged in the solar wind, is greatly affected by the intensities of solar emissions and civilization is troubled by communications, aurora, and weather disturbances. Forecasting sun activity is difficult because our knowledge of solar changes and their relation to the earth is limited.

A typical 90-day scenario is indicated in Figure 2.2-8 to illustrate activities and benefits of continuous on-orbit observation capabilities. The top scale indicates the sun's 27-day rotation cycles (N to N + 3). Keyed to this scale, a typical set of sun, earth, and STO crew activities is outlined beginning with average sunspot activity and then, on day 12, appearance of a large, highly active sunspot group on the rising equatorial limb. A flare erupts from this group and has intense emissions that affect earth's environment. Changes in sun activity and earth response continue for more than 60 days.

The crew forecasts the imminent flare and alerts the ground-based systems. All respond to this opportunity by stepping up their activities for data acquisition and analysis. The Skylab STO crew has 22 experiment instruments typically available. The crew is fully occupied during their duty periods in operating these experiments and some activities require simultaneous pointing at local areas on the sun as well as simultaneous viewing of sun and earth.

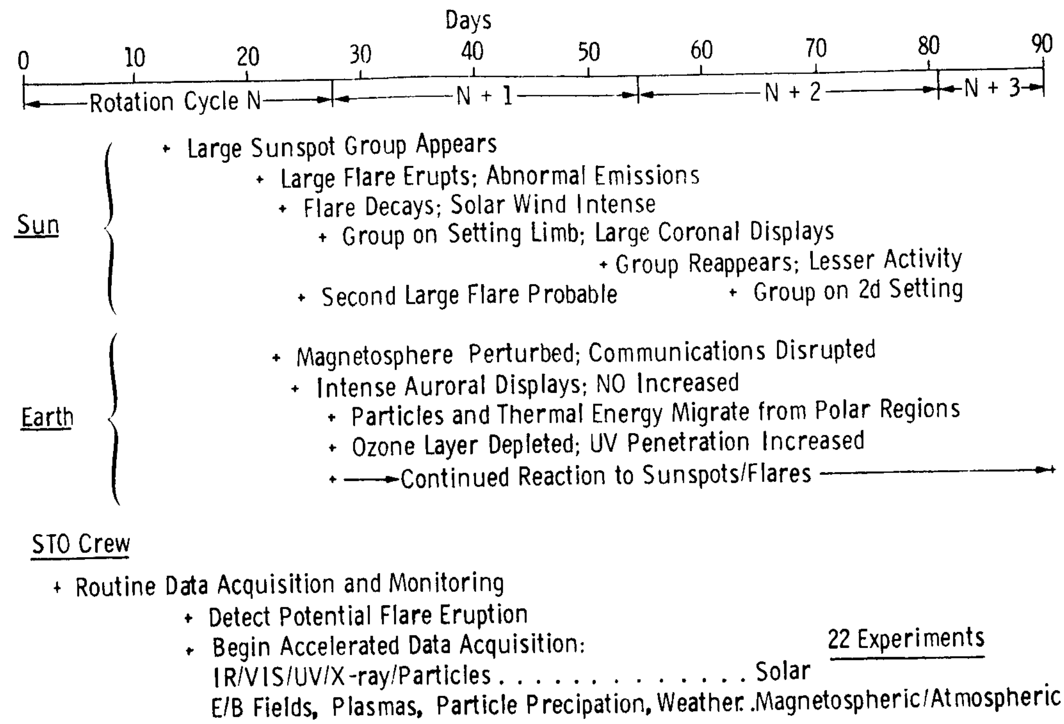


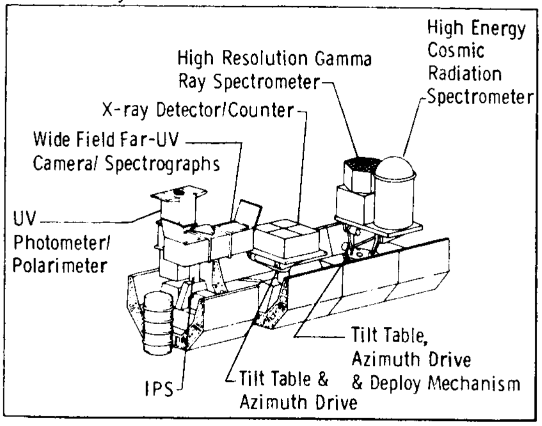
Figure 2.2-8 STO ... A 90-Day Mission Scenario

The STO objective is fulfilled efficiently with continuous manned activities that enable complex experiment operations and synergistic correlations of observations.

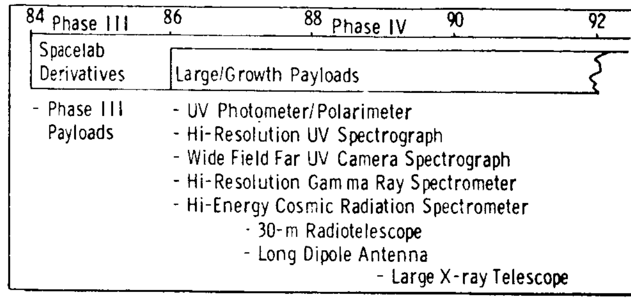
5) Astrophysics/Astronomy Requirements

The astrophysics/astronomy payload (Figure 2.2-9) is typical of the types of telescopes and collectors planned for the 1980 decade. Such instruments are required for conducting wide-field Far-UV Stellar surveys augmented by narrow field, high resolution data for studying specific stellar phenomena. These instruments require stable platforms for fine pointing, but otherwise the requirements shown in the figure are not stringent. They do, however, place a requirement to orient Skylab out of its original solar inertial attitude. Growth versions of this payload include large radiotelescopes and long dipole antennas which will be used for deep space investigations. These large instruments require on-orbit R&T activities that will enhance space construction techniques.

Phase III Payload



Growth to Phase IV



Summary Requirements--Phase III Representative Payload

Pointing Control	Stellar; 30 arc-s to 5 deg Accuracy; +0.25 arc-s Stability
Power	850 W Instrument Operating Power
Thermal Control	Thermal Canisters Required for Control of Gimbal-Mounted Instruments due to Precise Pointing Requirements; 220 to 370 K Expected Operating Range
Data Rates	480 kbps
Crew	1 Man for Each of 2 Shifts; EVA for Film Replacement

Figure 2.2-9 Astrophysics/Astronomy Requirements

6) Earth Viewing/Resources Requirements

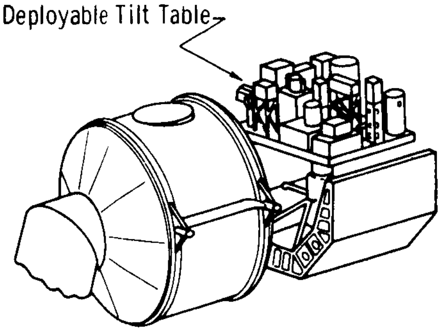
The existing equipment on Skylab for earth resources experiments (EREP) include several cameras, an L-band radiometer and a microwave radiometer/scatterometer and altimeter. These provided valuable data in the 1973-74 time period, but have become obsolescent as superior equipment has been developed and operated from earth orbits. The potential reuse of this Skylab equipment is therefore low, except for the S190B earth terrain camera that has continued value for general earth surveys.

Use of Skylab with new earth viewing instruments has been explored considering that during the 1980's other advanced satellite systems (e.g., advanced LANDSAT, SEASAT or NOSS) will be operating that will give global coverage to earth and ocean data acquisition. In general Skylab is believed to offer good potential as a platform for observing and analyzing mineral resources and urban development, but less potential for crop resources. Skylab with its mission specialist crew also offers good potential when used as a development and prototype test facility for new equipment to be later used in advanced earth-viewing programs.

The present Skylab reuse study considered possibilities that many rewarding research and technology activities can be supported by global observations of the earth from Skylab. Earth observations could include measurement of atmospheric properties such as pollutants, ocean dynamics such as ocean temperature and wave roughness, agricultural status such as farm and timber inventory surveys, and geological factors such as mineral locations and land use surveys.

A typical multi-purpose payload consisting of 15 instruments is defined in Figure 2.2-10 and represents the basis for establishing earth-viewing experiment requirements against which the capabilities of Skylab have been assessed. The instruments are shown mounted on a deployable tilt table to facilitate viewing from the Shuttle Payload Bay, but could also be pallet-mounted and attached to the Interface Module. The growth payloads will consist of very large, high resolution systems for improved monitoring and forecasting purposes.

Phase III Payload
Cluster of 15 Instruments
on Deployable Tilt Table



The 15 Instruments are from the "Consolidated Pallet Experiments;" S-2, S-3 OA Missions

Growth to Phase IV

84 Phase III 86 88 Phase IV 90 92

Spacelab Derivatives | Large/Growth Payloads

- Phase III Payloads
- ATMOS
- Atmospheric Lidar
- Solar Extinction Radiometer
- Large Format Camera
- Very Hi-Resolution VIS/IR System
- Storm Survey System
- Large-Scale Weather Survey System

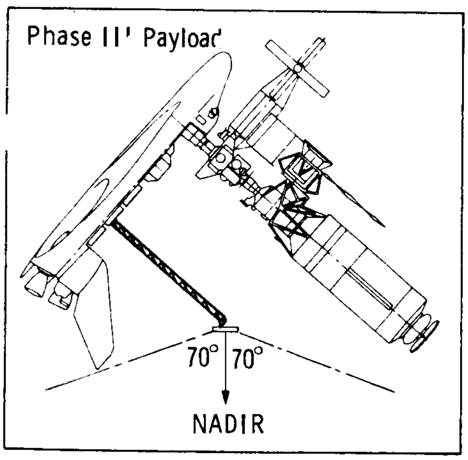
Summary Requirements--Phase III Representative Payload	
Pointing Control	Solar, Solar through Earth Limb, Nadir; ±12 arc-s to ±5 deg Accuracy; ±60 arc-s to ±1 deg Stability
Power	2.75 kW Instrument Operating Power for Selected Instruments
Thermal Control	Thermal Canisters Required; 270 to 325 K Expected Operating Range
Data Rate	10 Mbps
Crew	2 Men for Each of 2 Shifts

Figure 2.2-10 Earth Viewing Resources Requirements

7) Communication Programs Requirements

Orbiting antennas have grown larger and more complex as demands have been placed on communications satellites. Antennas of large variety have been used and proposed. These include single horns for global coverage, arrays of elements such as helices, Yagis and dipoles, multibeam offset-fed reflectors, microwave lens systems, and phased arrays of radiators. Future systems require platforms that can accommodate antennas with diameters ranging from 1m to 25m or more, and power ranging up to 20 kW or more.

A Boom Mounted Adaptive Multibeam Phased Array (AMPA) System is illustrated in Figure 2.2-11 as a representative payload for experiments in the 1980's. This system is capable of performing experiments on communications, direction finding, resolution, and to act as an orbital antenna test range. Boom deployment and thermal con-



Growth to Phase IV

84 Phase III 88 Phase IV 90 92

Spacelab 86

Derivatives | Large/Growth Payloads

- Phase III Payloads
  - 15 m Lens Antenna
  - Active Laser Radar
  - 3 m Optics
  - 30 m Thin Film Optics
  - 15 m Phased Array
  - 61 m Lens Antenna
  - Large-Scale Weather Survey System Development

Summary Requirements--Phase III Representative Payload	
Pointing Control	Nadir; 0.5 deg Accuracy; 180 arc-s Stability
Power	1160 W Instrument Operating Power
Thermal Control	Thermal Control for Instrument Stability/Cold Plates Required for Heat Dissipation; 273 to 328 K Expected Operating Range
Data Rate	1 Mbps
Crew	1 Man for 1 Shift per Day for Operations and Maintenance

Figure 2.2-11 Communication Programs Requirements

trol of these instruments is within present capabilities. Larger active and passive experiments associated with space construction, weather, navigation, and communications are anticipated as growth payloads. Ultimately, large payloads such as these are planned to be assembled at LEO and moved to a final operational geosynchronous orbit.

8) Payload Requirements Summary

Table 2.2-1 summarizes the physical requirements derived for representative payloads in each discipline area. This table includes Space Processing, Life Sciences, and Solar Power R&T for completeness. Requirements in these three areas were assigned to another contractor in a concurrent study.

Payload weights and sizes listed in Table 2.2-1 are all within the capability of Spacelab return capabilities. Pointing and stability accuracies require the use of stable platforms (instrument pointing systems) which have been anticipated for Spacelab. Power requirements of space processing and solar power R&T payloads although high can be accommodated by appropriate power module output scheduling. All data are within Skylab/Power Module Configuration capabilities.

Table 2.2-1 Payload Requirements Summary

Near Term 1984 - 1986 Representative Payloads

Payload Discipline	Weight, Tonnes	Size	Pointing/ Stability	Power kW	Crew Size	Data Rate, Mbps
Solar & Terrestrial Physics (Includes ATM)	3-15	4 Pallets	Sun, Nadir, Horizon 4 arc-s	4	4	12
Solar Terrestrial Observatory	3-15	4 Pallets	Sun, Nadir, Horizon 4 arc-s	8	4	12
Astrophysics/Astronomy	3-15	4 Pallets	Celestrial Sphere 30 arc-s	6	4	Low to 12
Earth Viewing	15	4 Pallets	Nadir/Horizon 20 arc-s	5	4	10 to 30
Communications	3-15	4 Pallets	Nadir, 1800 arc-s	5	4	Low
Space Processing	4-15	Module	None; $< 10^{-3}$g	8 to 15	3	Low
Life Sciences	3-15	Module	None; $<10^{-3}$g	4	3	Low
Solar Power R&T	2-15	Pallets & EVA	Sun, Nadir, Subsatellite	6 to 17	3	Low

The graphs in Figure 2.2-12 show typical average crew and power requirements for supporting such combined disciplines during the 1980s. Crew requirements grow from 3 in 1984, to 7 - 8 in 1987. Combined power requirements grow from 8 kW in 1984 to about 30 kW in 1987. Scheduling of mission/flight operations will necessarily be arranged to maintain power within Skylab/Power Module capabilities. Beyond 1987, depending on the growth of experiments toward advanced capabilities, crew and power augmentation may be required.

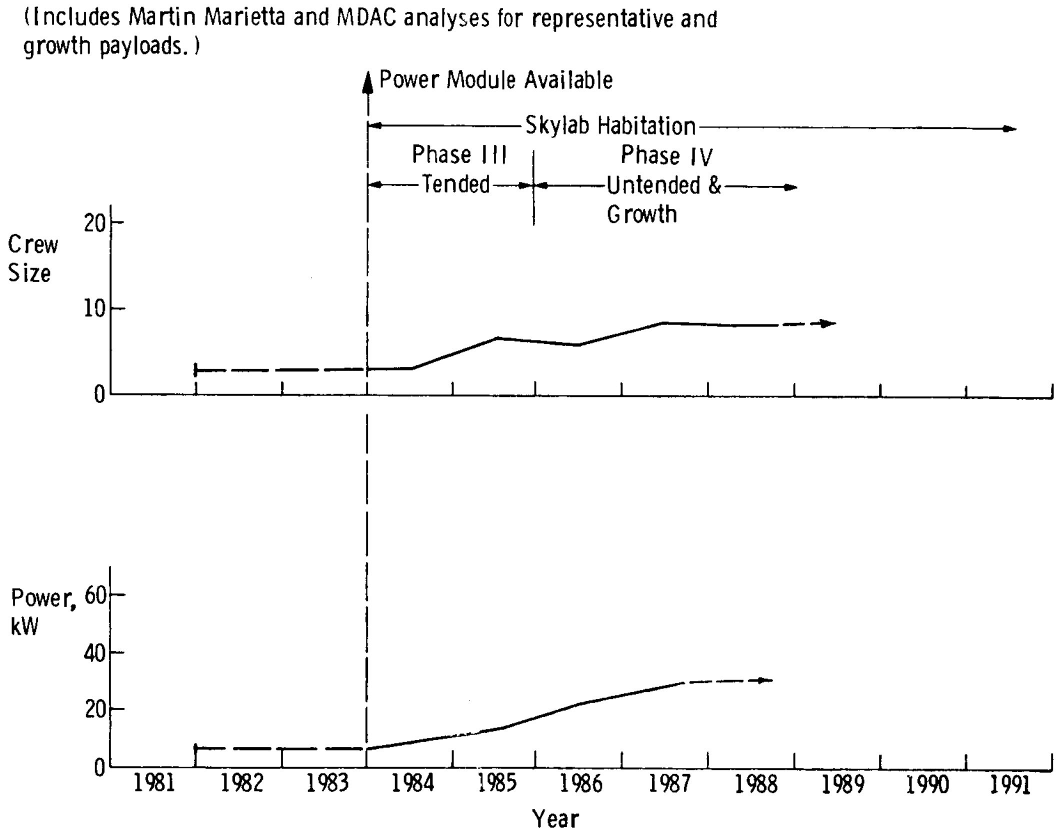


Figure 2.2-12 Summary Skylab Reuse Crew and Power Requirements

2.2.3 PAYLOAD ACCOMMODATIONS

1) Summary and Introduction

This section presents results of the analyses of the capabilities and constraints of Skylab Reuse. These Skylab accommodations for various payloads are focused on meeting requirements of the technical areas that were summarized in the preceding section.

Both the Shuttle-tended and the untended modes of operating the Skylab Cluster are addressed. Emphasis is given to the tended mode (Phase III, Figure 1-3) to demonstrate Skylab capabilities for supporting science requirements until the cluster is outfitted for untended operations (Phase IV). The time period required to operate Shuttle-tended could be quite short, depending on the speed at which total contended capability is implemented.

The analysis addressed requirements for all science and technology disciplines, in part to identify those disciplines that could be accommodated in early flights with least constraints. Considerable effort was made to determine the capabilities for controlling the Cluster attitudes to satisfy pointing requirements of solar, earth viewing and astronomy experiments. The results, presented in this chapter, show that the Shuttle-tended mode can be configured to accommodate those pointing requirements. The time available for data acquisition from instruments in the Orbiter payload bay (Option A, Figure 1-9) would be satisfactory although limited by CMG attitude control constraints and field-of-view shadowing. These limitations are relieved by placing instruments on pallets attached to the Cluster, (Option C, Figure 1-9). Further, they are eliminated by operating in the untended mode/Shuttle not attached to Cluster) because then the CMGs have much greater capabilities for attitude control and the field-of-view is not obscured by the Orbiter. Of course, experiments that do not require pointing, such as life sciences, structure demonstrations, and space processing, can be accommodated readily without concern for pointing attitude control.

In subsequent figures of Subsection 2), summary data results are presented for operations from the Orbiter bay (Option A, Shuttle tended) from pallets mounted on the Cluster (Option C, Shuttle tended) and from pallets with the Cluster untended (Phase IV, Figure 1-4). Pointing, power, thermal and communications capabilities are specifically addressed as the main drivers on Skylab reuse potentials, particularly for the disciplines requiring instrument pointing

Before presenting the more detailed results that are related to specific areas, some general Skylab capabilities may be noted as background information,as follows:

- The Skylab orbit after reboost will be compatible with 70 to 80% of current Spacelab missions.
- Longer mission durations achievable with Skylab have potential of lowering payload launch costs per unit viewing time and increasing instrument utilization.
- Two scientific airlocks and one EVA airlock are available, (assuming a new solar shield configuration to make the solar-SAL available)
- Skylab operates at less than 1/2 atmosphere, thus permitting EVA without prebreathing.
- Ten windows are available for photography, data collection and personal viewing.
- Low-g levels ($< 10^{-3}$ g's) are available.
- Film vaults are available.

In the Shuttle-tended mode (Phase III) with the 25 kW Power Module attached to the cluster, the following general capabilities can be utilized.

- A science crew of three to seven can be accommodated.
- Power Module provides nominally 7 to 8 kW of power (up to 30 kW at high Beta angles) for use by experiments.
- Up to 5 kW can be provided for payloads without the Power Module (3-man crew).
- Basic 1 to 3 deg attitude holding capability is available.
- Payloads are accommodated within the Orbiter Bay or attached to Skylab (Options A and C, Figure 1-9).
- Skylab ATM and life science equipment are workable (Option B, Figure 1-9).

In the untended mode (Phase IV) the following are generally available:

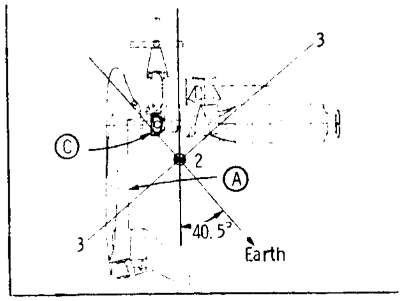
- A science crew of three to seven can be accommodated.
- Power to payloads >20 kW is available with Power Module and Skylab solar arrays.
- Continuous or near-continuous viewing can be provided for solar, stellar and earth observation.
- Payloads are attached to Skylab complex; two-body experiments possible.
- Skylab provides a stable free-flying platform under ground control.
- Skylab can be used as strongback for construction experiments.

This general background information is supported and amplified by the results of the accommodation analyses that are summarized in the remainder of this chapter. First, an overview is given in Subsection 2) of the Skylab Cluster capabilities to accommodate payloads located either in the Orbiter bay or on external pallets. Spacelab-derived payloads are shown that are typical for these operations. They can be accommodated on Skylab for extended periods of time beyond present Shuttle-alone capabilities. Modifications to Spacelab for extended life are therefore indicated in Subsection 3). Subsection 4) shows results of control and power analyses of a variety of Shuttle-tended cluster configurations that led to the selection of the baseline arrangement. Subsection 5) presents communication contact times with TDRS as affected by the cluster partially blocking the line-of-sight of antennas. Sub section 6) presents an overview of power capabilities to support cluster requirements during the evolutionary buildup program. The potential reuse of on-board Skylab experiments is discussed in Subsection 7, (defined as Option B in Figure 1-9). Further, growth add-on experiments and other potential uses of Skylab that can be accommodated are presented in Subsections 8) and 9).

2) Accommodations of Payloads Operated From the Cargo Bay or Attached to Cluster, Shuttle-Tended Mode

Assumptions and groundrules used for the accommodation analysis are shown in Table 2.2-2 . All analyses were based on the vehicle orientation shown in the Table, i.e., with the number 3 axis perpendicular to the orbit plane (POP). With the L-shaped cluster configuration, this orientation requires the equivalent of 4.9 Skylab CMGs for maneuvering and control. All power, communication line of sight to TDRSS, pointing, and

Table 2.2-2 Payload Capabilities and Constraints

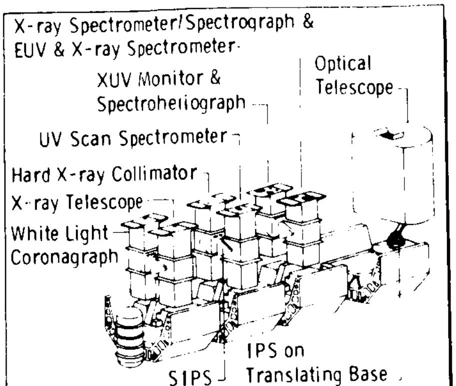


- Pointing and Attitude Control
  - 3 axis POP attitude at all times.
  - Maneuver about the 1 axis at $\beta = 0°$ using thrusters.
  - Aerodynamic torques not considered.
  - Masking of cluster included in pointing analysis.
- Power
  - Orbiter overhead 11 kW when attached to cluster.
  - Payload power requirement of 7 kW includes all support loads.
  - Crew power overhead above 3 crewmen 1 kW each.
  - Power Module power calculations based on system model described in "25 kW Power Module Preliminary Definition," Sept. 1977.
  - Skylab power capability assumes OWS solar array output of 5500 watts less 15%, and ATM solar array output of 1100 watts less 25%.
- Thermal
  - Heat rejection capability of Orbiter based on data from "25 kW Power Module Preliminary Definition," Sept. 1977, and JSC-07700.
  - View factors and shadowing from total Orbiter/Skylab/PM Cluster not considered.
  - No flash evaporator.
- Communications
  - 2 Orbiter antennas assumed.
  - Cluster masking included in antenna coverage.

thermal analyses were based on the 3 axis POP, with roll about the 3 axis to other orientations to meet various viewing requirements. When the orbit Beta angle reached zero degrees, a 180° maneuver about the 1 axis was assumed to enhance power generation.

Thermal and electrical loads were analyzed using the stated assumptions. The Orbiter overhead was reduced from 14 kW to 11 kW on the assumption that some Orbiter system, such as, avionics can be powered down when attached to the Cluster. Power Module power capability was computed using the energy balance equations, with loss and efficiency values taken from the model described in the referenced report. Skylab power capability was calculated assuming that 2 ATM array wings had been retracted for the tended mission. Thermal estimates are based on data from the referenced documents, and do not include total Cluster shadowing and view factors. Communications coverage assumed 2 Orbiter antennas in their normal locations and took into account Cluster masking.

Representative solar pointing payloads were compared to capabilities of the Skylab Cluster in the areas of pointing, power, thermal control, and communications. Attitude control constraints of the Cluster and the masking of fields of view by the Cluster elements were considered. The resulting capabilities and constraints are summarized in Figure 2.2-13.



Subsystem \ P/L Location	Orbiter Bay (Option A)	Pallet on Cluster (Option C)	Untended
Pointing - % of Time Instruments Can See Sun	Pallet - 1 > 80% - 2 > 90% - 3 > 95% - 4 ≈ 100%	100%	100%
Power	Power Margin Available Depending on Solar Observation Angle.	Positive Power Margin at All β Angles for 7 kW Payload & 3-Man Crew	Positive Power Margin at All β Angles, for Payload Up to 26 kW, 3-Man Crew.
Thermal - For 6.7 kW Payload & 11 kW to Orbiter	Observations Off Normal to Sun Appear Feasible; More Analysis Needed.	Observations Unconstrainted with Orbiter Lower Surface to Sun	Payload Heat Rejection through Power Module: 6.7 kW
Communications - % of Time Line of Sight to TDRSS; Both Orbiter Antennas	- 39% to 94%	-50% to 95%	Ku Band System Needed for 12 Mbps Rates.

Figure 2.2-13 Payload Capabilities and Constraints--Solar Pointing

Instruments mounted in the Orbiter Bay usually can be pointed at the sun (assuming payload gimballing). Those sensors mounted closest to the Orbiter cabin wall are masked somewhat more than other locations. However, viewing is available most of the time. Instruments mounted on a pallet attached to the cluster are relatively unconstrained from a power and thermal control point of view, both for shuttle tended and untended modes of operation.

Solar viewing from the cargo bay may be feasible at some angles. However, the analyses is incomplete. Based on interpolation between two widely separated thermal data points for heat rejection from the Orbiter radiators, there should be viewing angles from the payload bay that simultaneously satisfy pointing, power, and thermal control requirements. For example, if the Orbiter can reject its head load (11 to 14 kW) at an angle within 25 deg of the perpendicular line to the sun from the cargo bay, then pointing and power requirements can be satisfied 100% of the time. Payload heat (to 6.7 kW) must be rejected through the power module radiators in this mode. Specific Orbiter components (e.g., landing gear hydraulics) and the OWS radiator system were not considered in the analysis. Periodic thermal conditioning maneuvers may be required which are similar to those of Shuttle/Spacelab.

Line of sight from the Orbiter antennas to TDRS is available during most orbit periods for the tended mode. With the untended mode, a high data rate system is required on the Cluster, since the baseline Power Module system can transmit only 64 kbps through the TDRS link. High gain, steerable antennas are needed. Data rates for the representative payloads drive the system toward Ku Band capabilities.

Two examples of masking diagrams are shown in Figure 2.2-14, one for the Orbiter TDRSS antennas and one for a solar payload operated from the Orbiter cargo bay. These diagrams define the unblocked view of antennas or instruments for pointing at their objectives. Azimuth and elevation values are given in Shuttle coordinates. Similar diagrams were prepared for other payloads, assuming operation both from the cargo bay and attached on pallets to the Interface Module. This information is then a basis for deriving the specific pointing capabilities (percent viewing time available).

Figure 2.2-15 shows summary results for pointing, power, thermal and communications for representative earth-pointing payloads. Continuous earth pointing of instruments is possible from the Orbiter Bay or from a pallet attached to the Cluster when operating at high β angles. For $\beta < |40^{\circ}|$, power constraints cause viewing time to be reduced.

The atmospheric/magnetospheric payload has a variety of pointing requirements ranging from pointing to the local vertical, to the earth horizon and to magnetic field lines, with both narrow and

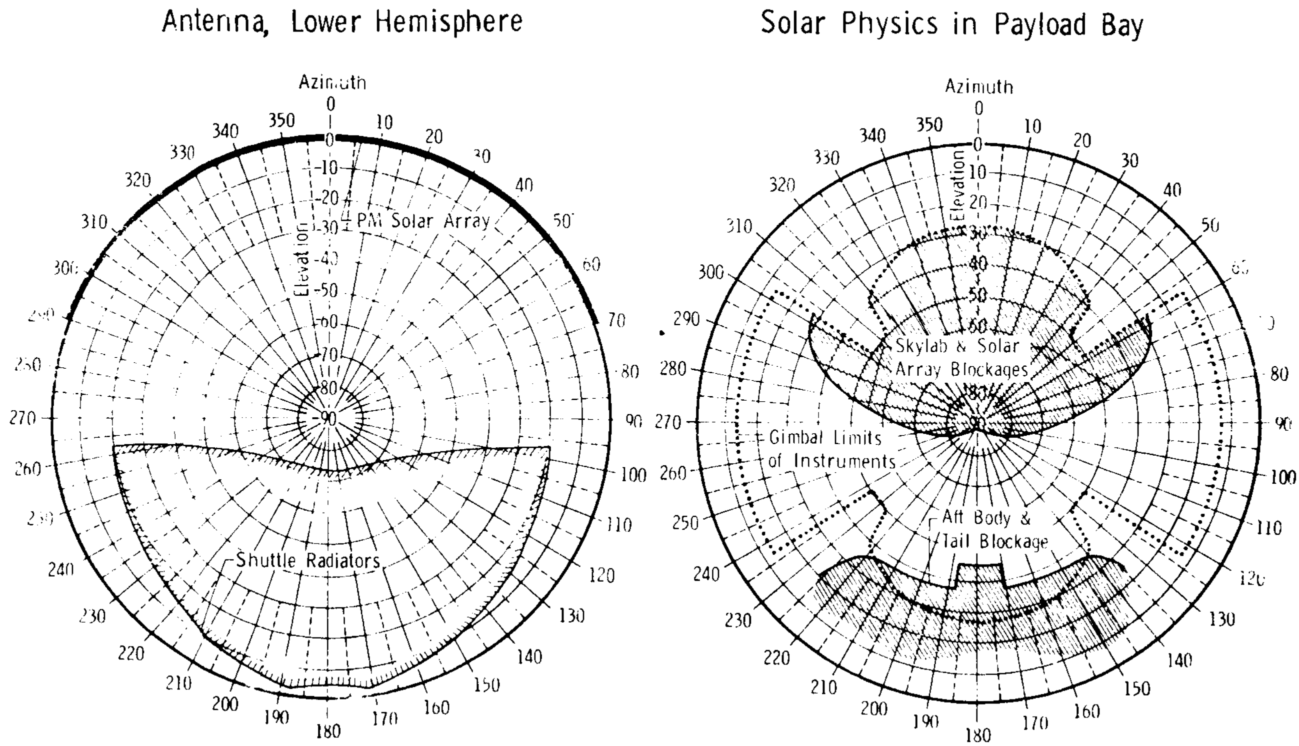
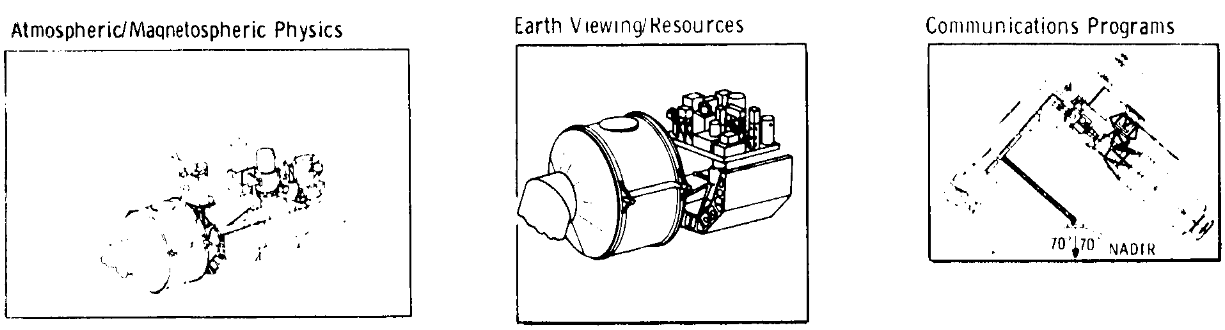


Figure 2.2-14 Field of View Examples - Orbiter Antenna and Solar Physics



Subsystem	Orbiter Bay (Option A)	Pallet on Cluster (Option C)	Untended
Pointing - % of Time Earth Nadir Can Be Seen	100%	100%	100%
Power	OK for EREP Type Passes Continuous for High Angles (-40>β>40)		Positive Power Margins Available to Approximate 21 kW
Thermal - For 6.7 kW Payload & 11 kW to Orbiter	OK with Payload Heat Rejection to Power Module (6.7 kW)		
Communications - % of Time Line of Sight to TDRSS; Both Orbiter Antennas	- 31% to 92%	- 31% to 92%	Data Rates Require Ku Band System

Figure 2.2-15 Payload Capabilities and Constraints - Earth Pointing

wide fields-of-view. Figure 2.2-16 shows typical masking by the Skylab and the Shuttle for narrow to medium beams of instrument packages 1, 2 and the Laser Sounder. Packages 1, 2 and the Laser Sounder are shown on the left side of Figure 2.2-15 from the fore to the aft pallet, respectively. Because of the space and tilt-table geometry limitations, a rather extensive physical interference of the Laser Sounder with the Shuttle aft bulkhead occurs. The SEPAC (Space Experiment With Particle Accelerators) package of instruments requires a 90 deg conical field-of-view, and therefore exhibits only a very limited area of blockage-free pointing when operated from the payload bay.

Figure 2.2-17 shows masking as seen from a pallet mounted on the Interface Module. The pallet is docked to the side port so that the pallet vertical points to the earth and the longitudinal axis

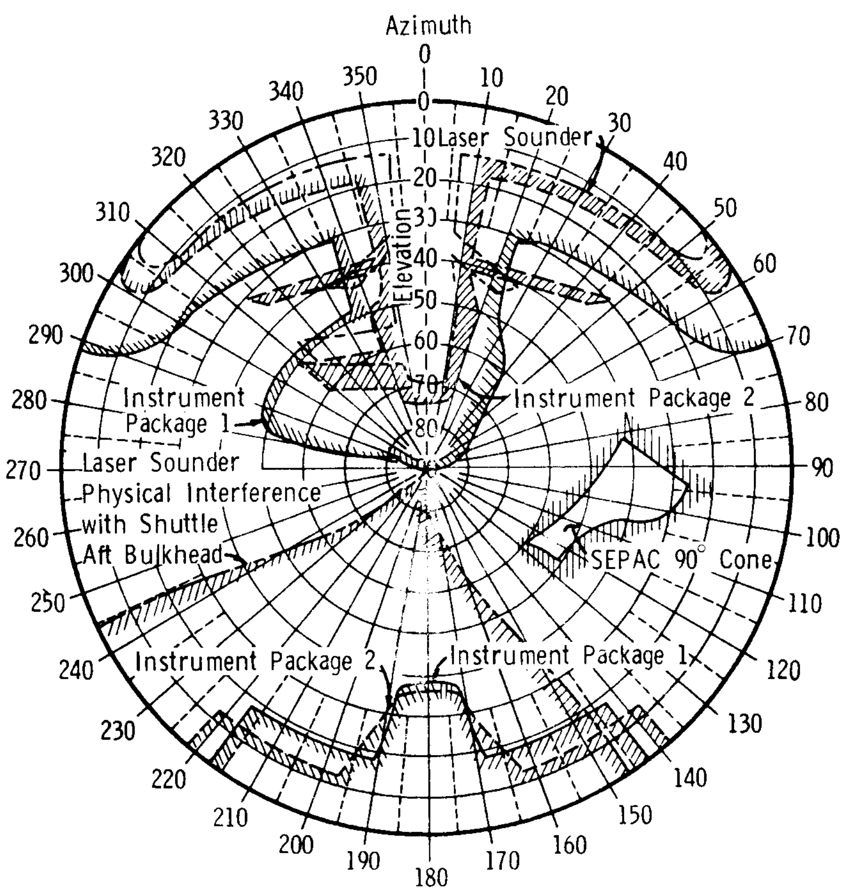


Figure 2.2-16 Atmospheric/Magnetospheric Physics Payload in Shuttle Payload Bay

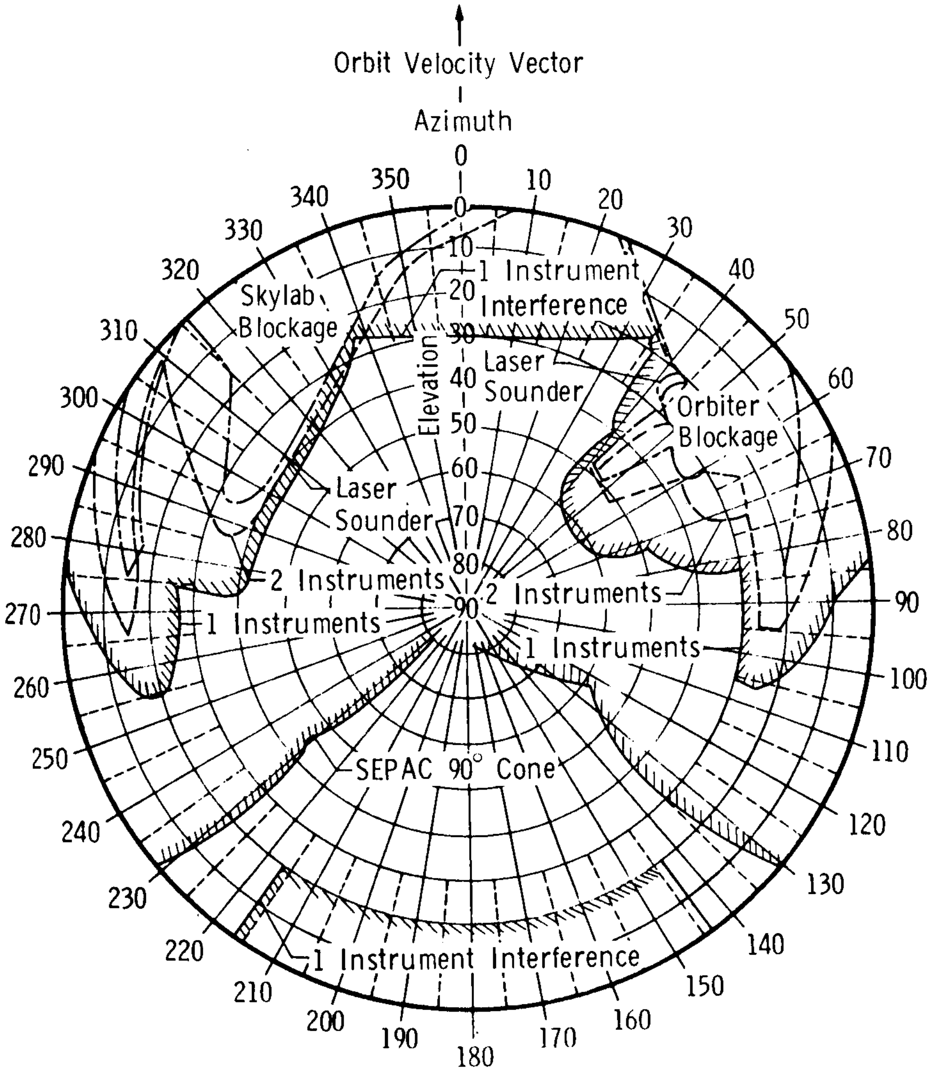
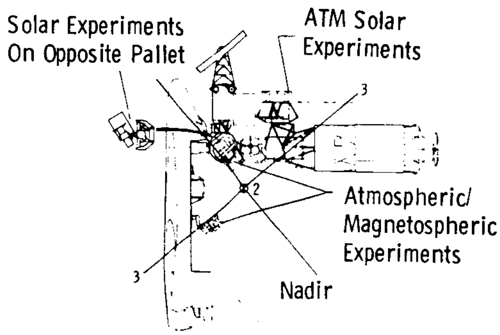


Figure 2.2-17 Field of View, Atmospheric/Ionospheric Physics Payload on Docked Pallet

of the pallet is parallel to the Orbit Velocity Vector. The coordinate system of the blockage diagram is selected accordingly with azimuth zero in the direction of the Orbit Velocity Vector and elevation 90 deg pointing to earth. The Skylab and Orbiter blockage again is shown for instrument groups 1, 2, and the Laser Sounder. These payloads, as well as the SEPAC group, have a much expanded field-of-view compared to the Shuttle Bay arrangement shown in the preceding figure.

The typical payload of communication programs that was shown on the right side of Figure 2.2-15 is an AMPA (Adaptive Multibeam Phased Array). This experiment antenna is mounted on a pallet or, as the figure illustrates, on a boom emerging from the Payload Bay. The boom provides clearance from the Orbiter so that the wide 70-deg field-of-view requirements can be completely satisfied.

The Solar Terrestrial Observatory (STO) requirements can be accommodated on Skylab, as pointing with different instruments is possible in both solar and nadir directions at the same time (Figure 2.2-18). Solar payloads can be operated (1) from the Cargo Bay (provided that the bay is oriented off the perpendicular to the sun line); (2) mounted on the Power Module Solar Array Boom or; (3) attached to the Interface Module on pallets. More analysis is needed to determine the range of permissible angles which will simultaneously satisfy pointing, power, thermal control, and communications requirements. The Cluster can be



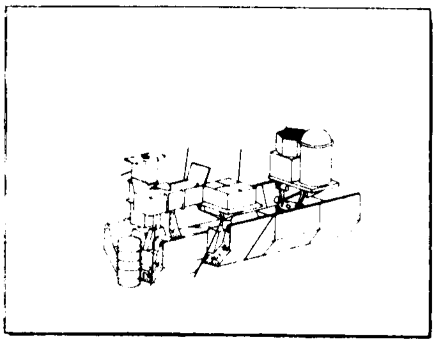
Subsystem \ P/L Location		Orbiter Bay (Option A)	Attached to Cluster (Option C)	Untended
Pointing - % Viewing Time		Near 100% - Solar or Earth →	→	→
Power	Solar	Power Margin Available Depending on Solar Observation Angle.	7 kW Minimum	Up to 26 kW
	Earth	OK for EREP Type Passes	EREP Type Passes OK; Continuous If Gimballed →	→
Thermal		Observations off Normal to Sun Appear Feasible; More Analysis Needed	Observations Unconstrained with Orbiter Lower Surface to Sun	Reject Heat through Power Module (Up to 6.7 kW)
Communications % Time Line of Sight to TDRSS		Solar 39 to 94% Earth 31 to 92%	Solar 50 to 95% Earth 31 to 92%	Ku-Band System Needed for High Data Rates.

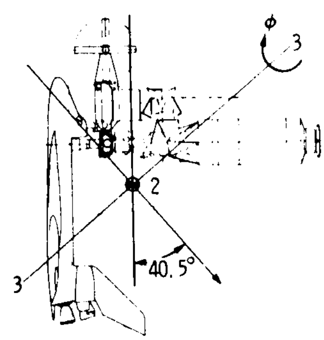
Figure 2.2-18 Payload Capabilities and Constraints for Solar Terrestrial Observatory

continuously oriented along a major axis toward nadir. In the nadir orientation at high Beta angles, the Power Module produces adequate power to meet Orbiter/Skylab/Payload power requirements.

Results of analyses of payloads requiring stellar pointing are summarized in Figure 2.2-19. The Skylab provides good accommodations, as an average of 8 hours observation time per day is available for a large set of starfields. Power is adequate to meet mission objectives. Heat rejection from the combined Orbiter/Power Module radiator systems should meet requirements. Communications coverage is adequate for most attitudes, and could be augmented by data storage and playback, if necessary.

The Astrophysics payload considered in this study is typical of stellar pointing instruments having wide angle field-of-view. In





Subsystem	Orbiter Bay (Option A)
Pointing - Viewing Time as % of Total Star Hours Available	- Case A - 13% - Case B - 22% - Case C - 16% - Case D - 12%
Power - β at Which Positive Power Margin Exists for 6.7-kW Payload & 3-Man Crew	8 hrs/day (average) for 10 example starfields
Thermal	- OK with Solar Vector Off Normal to Orbiter Bay
Communications - % of Time Line of Site to TDRSS; Both Orbiter Antennas	Can accommodate all needed viewing directions by scheduling over Beta cycle

Case A is $\phi = 0°$
Case B is $\phi = 180°$
Case C is $\phi = 90°$
Case D is $\phi = 270°$

10 of 11 Example

Starfields Accommodated

Figure 2.2-19 Stellar Pointing Payload Requirements and Constraints the usual Spacelab missions, these instruments are mounted on the normal, stationary pallets. However, in order to explore the maximum flexibility in pointing, some of them are assumed in this study to be mounted on a tilting rotating table. For preparing the masking diagram of Figure 2.2-20, it was assumed that the instruments have a narrow field-of-view and are SIPS mounted. These show the typical Skylab blockage. The pallet 2 instrument has a medium beam width ($\pm 6^{\circ}$), but because it is farther aft, it has somewhat less Skylab blockage. The critical instruments are numbers 3 and 4, which are assumed mounted together on the tilt table on the aft 2 pallets. No. 3, which has a $\pm 30^{\circ}$ field-of-view, is very limited in pointing directions, whereas No. 4 instrument with a $\pm 60^{\circ}$ field-of-view has only two singular points in the viewing hemisphere. For completeness, limit curves for $\pm 50^{\circ}$ and $\pm 40^{\circ}$ field-of-view for this instrument are also shown.

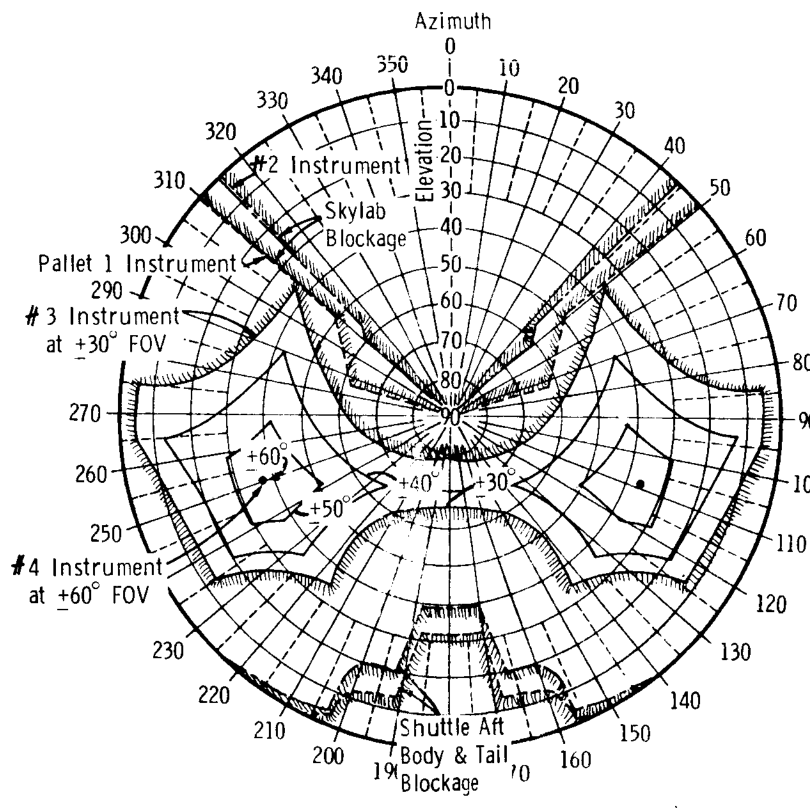


Figure 2.2-20 Field of View for Astrophysics Payload in Shuttle Payload Bay

With these data available, the star viewing time (Table 2.2-3) was calculated for eleven star fields typically situated on the celestrial sphere (reference, Astrophysics Payloads for Spacelab, GSFC, Oct. 1976). The viewing instrument was assumed to be mounted in the center of the Orbiter Bay.

Table 2.2-3 Celestial Pointing from Payload Bay

Star Viewing Time

	% of Available Hours (24 hr/day)			
Star	Case A (ϕ = 0)	Case B (ϕ = 180)	Case C (ϕ = 90)	Case D (ϕ = 270)
1	19	4	31	27
2	44	40	38	0
3	0	14	0	0
4	8	50	42	0
5	0	56	52	0
6	0	0	0	0
7	4	20	4	14
8	4	4	4	0
Hyades	9	52	0	52
Virgo	37	0	0	36
Galaxy Center	18	0	0	4
Average Viewing Time	13%	22%	16%	12%

Computer programs were used to generate line-of-sight vectors to each of the star fields and to determine their occultations by the earth. The vehicle masking constraints were then introduced to determine the available viewing time. Calculations were made for each of the star fields as a function of Beta angle and roll angle (about the 3 axis POP). As shown in Table 2.2-3, roll is a means to enhance the viewing time. It can be further enhanced by a maneuver of 180 deg about the 1 axis.

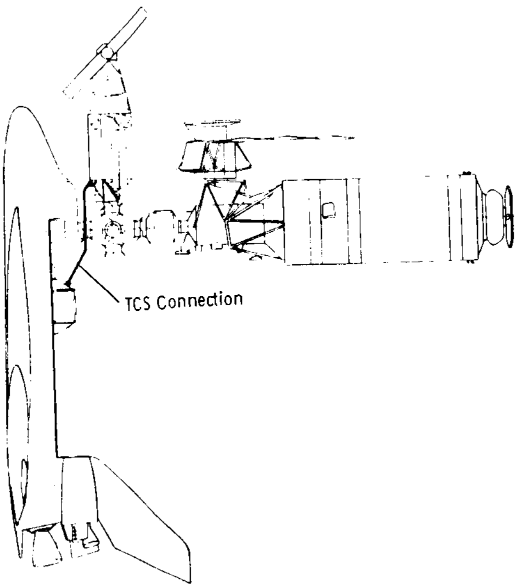
Space Processing and Life Sciences have no target pointing requirements and generally have low data transmission rates. The Cluster can therefore be oriented to maximize power generation and to reject heat. Low gravity levels ($\lesssim 10^{-3}$ g) are needed. These were provided during the original Skylab missions and should be possible during Reuse.

Payloads demonstrating Solar Power Development/Large Structure Assembly can be operated on Skylab. In this case, the OWS acts as a strongback, with rails and fixtures added to demonstrate jointing, fastening, alignment using both astronauts and machinery, such as, the Space Crane. Experiments can be conducted both internally and externally to Skylab. A minimum control attitude would be held during construction and tests conducted at favorable Beta angles to maximize power. The demonstration power unit could then be used to supplement the Power Module for growth payloads.

3) Spacelab Modifications Required for Extended Life Experiments

Spacelab is designed for a one week nominal mission operated from the Orbiter Cargo Bay. Operations from Skylab will be of longer duration and may require removal from the cargo bay and attachment to the Interface Module. ERNO, described modifications needed to extend Spacelab mission duration (reference, The Use of Spacelab Elements Within Different Possible Steps Towards A Space Platform, ERNO, Jan. 1978). We have added several items to the ERNO definition, regarding 1) mechanical, fluid, electrical, and gas interfaces with the Interface Module and 2) trusses to tie pallets to the Spacelab Module. These modifications are defined in Figures 2.2-21 and 2.2-22 for payload bay and Cluster Docked Payloads, respectively.

In Payload Bay



Modifications

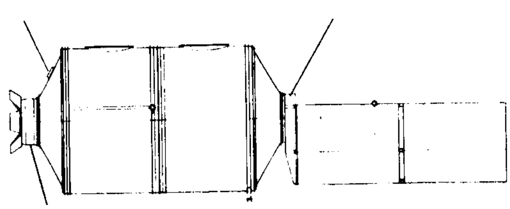
Module Only / Module + Pallet	Weight (Kg)
• Improve Reliability	30
• Change CO_2 Removal System	--
• Add Water/Freon Components	167
• Penetration of End Cone (TCS)	--

Pallet Only	Weight (Kg)
• Improve Reliability	28
• Igloo Pressure Control	6
• Add Water / Freon Components	94

Figure 2.2-21 Spacelab Modifications for Extended Life Missions--Payload Bay

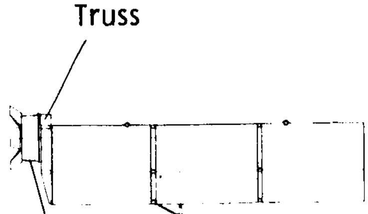
Docked To Cluster

Module or Module + Pallet



Modifications	Weight (Kg)
• Improve Reliability	30
• Change CO_2 Removal System	--
• Add Water/Freon Components	16
• Penetration of End Cone (TCS)	--
• Add Docking Adapter to End Cone	422
• Add Grapple Fittings	--
• Add Truss For Mounting Pallet to Module	

Pallets only



• Improve Reliability	28
• Igloo Pressure Control	6
• Add Water/Freon Components	94
• Add Grapple Fittings	
• Add Docking Adapter	422
• Add Truss For Mounting Pallet To Docking Adapter	

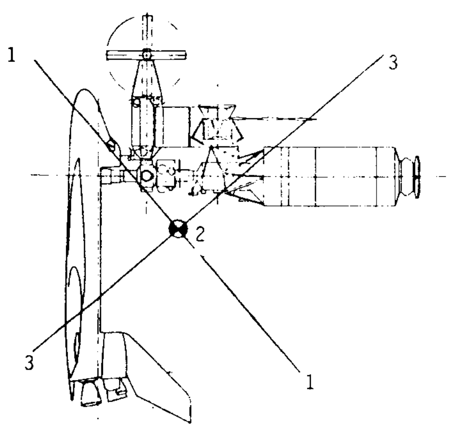
Figure 2.2-22 Spacelab Modifications for Extended Life Missions--Docked

4) Effects of Various Cluster Configurations on Attitude Control and Available Power, Shuttle-Tended Mode.

Three basic Cluster configurations consisting of the Orbiter, Skylab, and Interface Module were studied both with and without the Power Module attached. These six configurations with results of the CMG control analysis and electrical power analysis that included shadowing effects are presented in Figures 2.2-23, 24, 25, 26, 27 and 28. The figures also give an estimate as to how long a POP orientation can be maintained using only Orbiter RCS control.

Considerations for power reductions were arrived at by turning off various items and by power management of others, resulting in a savings of approximately 1300 watts during manned operations. For example, the ATM canister thermal controls, camera control units, the food preparation heaters and the OWS wall heaters were turned off; the communications air-to-ground system was restricted to 90 minutes daily and lights were turned off when not absolutely needed by the crew. A similar management approach for unmanned operations saved over 900 watts. Resulting power values would be 2.8 KW Manned and 2.0 KW Unmanned.

Gravity Gradient Torques acting on the very large inertias cause extreme momentum accumulation due to bias torques even with very small deviations from a POP attitude. Data on the figures indicate that a worst case Solar Inertial Attitude can be held a maximum of



POWER REQUIREMENTS

	SKYLAB**	ORBITER	SPACELAB
MANNED OPS (HABITABILITY)	4.1 KW	10-14 KW	2-4 KW
UNMANNED OPS	2.9 KW	--	2-4 KW

POWER AVAILABLE

ORIENTATION & CONFIG	POWER*
3-POP	27.3 TO 31.8 KW
SOLAR INERTIAL (W/O ORBITER)	28.6 TO 30.6 KW

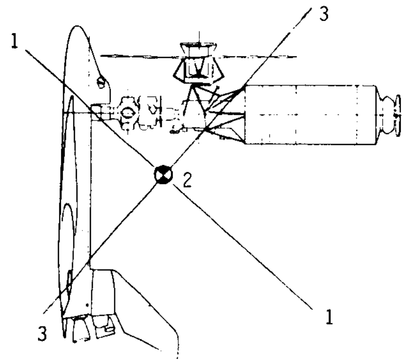
*BETA ANGLE DEPENDENT

ATTITUDE CONTROL

- CONTINUOUS SOLAR POINTING OF SKYLAB PANELS NOT PRACTICAL
  - APPROX 4 MINUTES POSSIBLE WITH 5 CMG's
  1-POP (-26208 nmsec) = 8.4 CMG EQUIVALENT
  2-POP (19560 nmsec) = 6.3 CMG EQUIVALENT
  3-POP (6835 nmsec) = 2.2 CMG EQUIVALENT
- CAN OPERATE SOLAR INERTIAL DURING DETACHED SHUTTLE PERIODS
- HOLD WITH ORBITER RCS: APPROX 16-18 DAYS IN 3-POP

** Could be powered down to 2.8 KW Manned and 2.0 KW Unmanned

Figure 2.2-23 Power and Attitude Control - Baseline with Power Module



ATTITUDE CONTROL

POWER REQUIREMENTS

	SKYLAB**	ORBITER	SPACELAB
MANNED OPS (HABITABILITY)	4.1 KW	10-14 KW	2-4 KW
UNMANNED OPS	2.9 KW	--	2-4 KW

POWER AVAILABLE

ORIENTATION & CONFIG	POWER*
1-POP	2.4 TO 8.7 KW
SOLAR INERTIAL (W/O ORBITER)	3.6 TO 9.7 KW

*BETA ANGLE DEPENDENT

- CONTINUOUS SOLAR POINTING OF SKYLAB PANELS NOT PRACTICAL
  - APPROX 3 MINUTES POSSIBLE WITH 3 CMG's

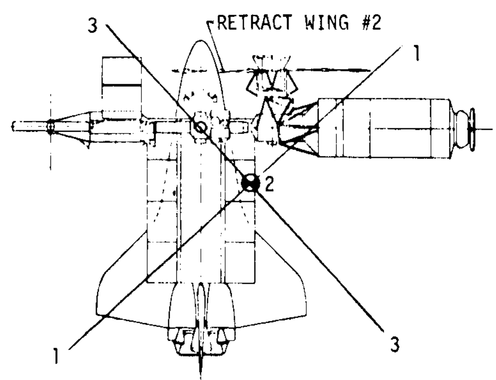
  1-POP (-18585 nmsec) = 6 CMG EQUIVALENT

  2-POP (-12506 nmsec) = 4 CMG EQUIVALENT

  3-POP (6080 nmsec) = 2 CMG EQUIVALENT
- ROTATE ABOUT AXIS (3) TO HOLD PANELS TOWARD SUN
- CAN OPERATE SOLAR INERTIAL DURING DETACHED SHUTTLE PERIODS
- HOLD WITH ORBITER RCS: 10-60 DAYS IN 3-POP

**** Could be powered down to 2.8 KW Manned and 2.0 KW Unmanned**

Figure 2.2-24 Power and Attitude Control - Baseline Configuration without Power Module



ATTITUDE CONTROL

POWER REQUIREMENTS

	SKYLAB**	ORBITER	SPACELAB
MANNED OPS (HABITABILITY)	4.1 KW	10-14 KW	2-4 KW
UNMANNED OPS	2.9 KW	--	2-4 KW

POWER AVAILABLE

ORIENTATION & CONFIG.	POWER*
1-POP	27.8 TO 31.8 KW
SOLAR INTERTIAL (W/O ORBITER)	28.6 TO 33.1 KW

*BETA ANGLE DEPENDENT

- CONTINUOUS SOLAR POINTING OF SKYLAB PANELS NOT PRACTICAL
  - APPROX 5 MINUTES POSSIBLE WITH 5 CMG's

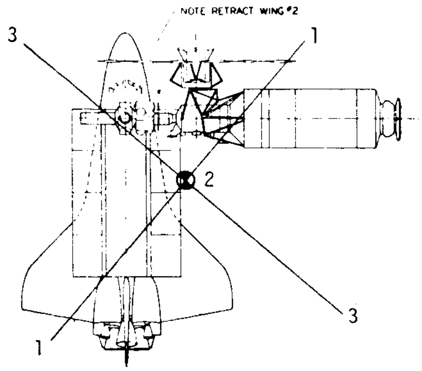
  1-POP (-9345 nmsec) = 3.0 CMG EQUIVALENT

  2-POP (-11760 nmsec) = 3.8 CMG EQUIVALENT (NOT CONSISTENT WITH POWER MODULE DEGREE OF FREEDOM)

  3-POP (21105 nmsec) = 6.8 CMG EQUIVALENT
- CAN OPERATE SOLAR INERTIAL DURING DETACHED SHUTTLE PERIODS
- HOLD WITH ORBITER RCS: 14-25 DAYS IN 1-POP

**** Could be powered down to 2.8 KW Manned and 2.0 KW Unmanned**

Figure 2.2-25 Power and Attitude Control - T Configuration with Power Module



POWER REQUIREMENTS

	SKYLAB **	ORBITER	SPACELAB
MANNED OPS (HABITABILITY)	4.1 KW	10-14 KW	2-4 KW
UNMANNED OPS	2.9 KW	--	2-4 KW

POWER AVAILABLE

ORIENTATION & CONFIG	POWER*
3-POP	2.4 TO 7.3 KW
SOLAR INERTIAL (W/O ORBITER)	3.6 TO 8.1 KW

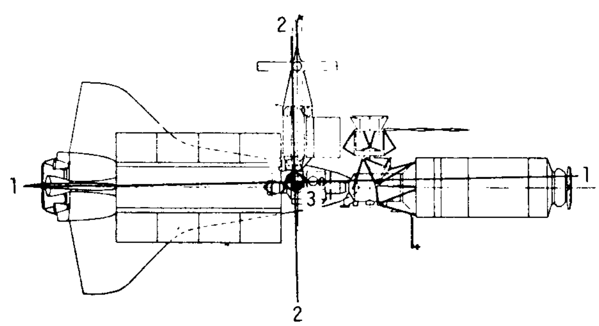
*BETA ANGLE DEPENDENT

ATTITUDE CONTROL

- CONTINUOUS SOLAR POINTING OF SKYLAB PANELS NOT PRACTICAL
  - APPROX 3 MINUTES POINTING POSSIBLE WITH 3 CMG's
  - 1-POP (-19962 nmsec) = 6.4 CMG EQUIVALENT
  - 2-POP (-12990 nmsec) = 4.2 CMG EQUIVALENT
  - 3-POP (6962 nmsec) = 2.3 CMG EQUIVALENT
- ROTATE ABOUT AXIS (1) TO MAINTAIN SOLAR PANELS TOWARD SUN (APPROX MONTHLY)
  - USE ORBITER RCS/SKYLAB TACS SINCE CMG MANEUVER NOT PRACTICAL (26 CMG EQUIVALENT)
- HOLD WITH ORBITER RCS: 16-35 DAYS IN 3-POP MODE
- CAN OPERATE SOLAR INERTIAL DURING DETACHED SHUTTLE PERIODS

**** Could be powered down to 2.8 KW Manned and 2.0 KW Unmanned**

Figure 2.2-26 Power and Attitude Control - T Configuration without Power Module



POWER REQUIREMENTS

	SKYLAB **	ORBITER	SPACELAB
MANNED OPS (HABITABILITY)	4.1 KW	10-14 KW	2-4 KW
UNMANNED OPS	2.9 KW	--	2-4 KW

POWER AVAILABLE

ORIENTATION & CONFIG	POWER*
1-POP	26.7 TO 23.6 KW
SOLAR INERTIAL (W/O ORBITER)	28.6 TO 31.6 KW

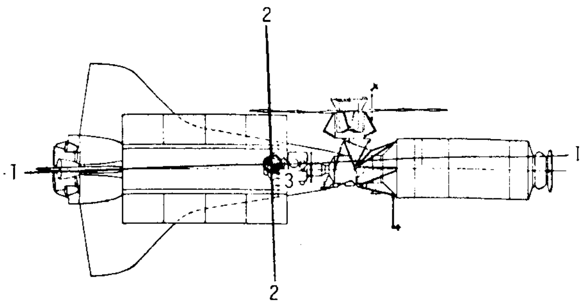
*BETA ANGLE DEPENDENT

ATTITUDE CONTROL

- CONTINUOUS SOLAR POINTING OF SKYLAB PANELS NOT PRACTICAL
  - APPROX 3 MINUTES POINTING POSSIBLE WITH 5 CMG's
  - 1-POP (-1186 nmsec) = 0.4 CMG EQUIVALENT
  - 2-POP (-39248 nmsec) = 12.7 CMG EQUIVALENT
  - 3-POP (38062 nmsec) = 12.3 CMG EQUIVALENT
- CAN OPERATE SOLAR INERTIAL DURING DETACHED SHUTTLE PERIODS
- HOLD WITH ORBITER RCS: 18-70 DAYS IN 1-POP

**** Could be powered down to 2.8 KW Manned and 2.0 KW Unmanned**

Figure 2.2-27 Power and Attitude Control - In Line Configuration with Power Module



POWER REQUIREMENTS

	SKYLAB**	ORBITER	SPACELAB
MANNED OPS (HABITABILITY)	4.1 KW	10-14 KW	2-4 KW
UNMANNED OPS	2.9 KW	--	2-4 KW

POWER AVAILABLE

ORIENTATION & CONFIG	POWER*
1-POP	2.5 TO 5.1 KW
SOLAR INTERTIAL (W/O ORBITER)	3.6 TO 9.7 KW

*BETA ANGLE DEPENDENT

ATTITUDE CONTROL

- CONTINUOUS SOLAR POINTING OF SKYLAB PANELS NOT PRACTICAL
  - APPROX 2 MINUTES POINTING POSSIBLE WITH 3 CMG's
    1-POP (359 nmsec) = 0.1 CMG EQUIVALENT
    2-POP (-39393 nmsec) = 12.6 CMG EQUIVALENT
    3-POP (39033 nmsec) = 12.5 CMG EQUIVALENT
- ROTATION AROUND AXIS (2) WILL NOT HELP SOLAR POINTING OF PANELS
- CAN OPERATE SOLAR INERTIAL DURING DETACHED SHUTTLE PERIODS
- HOLD WITH ORBITER RCS: 18-200 DAYS IN 1-POP

** Could be powered down to 2.8 KW Manned and 2.0 KW Unmanned

Figure 2.2-28 Power and Attitude Control - In Line Configuration without Power Module

5 minutes using 5 CMG control. Therefore, the Cluster must be operated in a principal axis POP orientation, which gives only cyclic momentum profiles. As the data on the figures indicate, the choice of the best OPO orientation makes it feasible to handle the cyclic peaks with a reasonable number of ATM CMGs. Figure 2.2-23 shows the Cluster configuration that has received the most attention. As indicated on the figure, the cyclic momentum peak with the 3 axis POP is equivalent to 2.2 ATM CMGs. However, 5 CMGs are recommended as a baseline configuration to allow for requirements not considered in Figure 2.2-23 such as aerodynamic disturbances, small maneuvers, and small momentum biases. There are other constraints (power, thermal, target viewing) which affect Cluster attitude requirements, but a principal axis POP orientation must be maintained.

The Apollo Telescope Mount (ATM) can gimbal $\pm 2^{\circ}$. To view the sun with these instruments, the original solar inertial attitude is required. Continuous pointing is possible with the Orbiter detached. However, with the Orbiter attached, continuous pointing of the ATM toward the sun cannot be done under CMG control alone, as saturation of the CMG system would occur in approximately 5 minutes. Longer holding times require thrusters to provide CMG desaturation and to perform maneuvers. The Orbiter thrusters can provide this capability for up to six days with the available Orbiter propellants.

Partial viewing periods can be obtained in the 3-POP attitude due to the passage of the ATM through the sunline (Figure 2.2-29). This can give an estimated 25-47 days of viewing time each year using the ±2 degree offset afforded by the EPC system. The frequency and duration of these viewing times depends on the Beta angle profile.

Adjusting the inertia by having large movable weights on booms would make it possible to hold the ATM solar inertial attitude continuously with the CMG system. If one can afford the weight penalty, such inertia balance is a method to enhance cluster control.

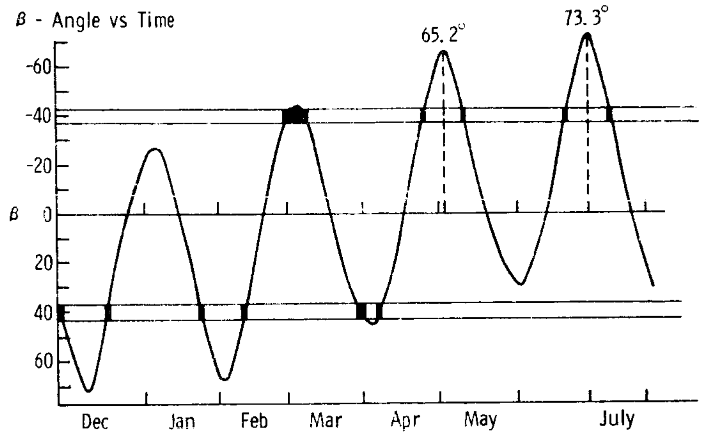
Baseline Configuration

Viewing:

- 1 to 7 Days Continuous (25 to 47 Days/1 Year) in 2° Bands at Beta = +40.5 and -40.5
- Continuous without Orbiter Attached

Reuse Benefit:

- Complements Solar Polar Mission
- Can Save Part or All of a Payload Cost



Options to Provide Continuous Pointing

Thruster Control	- TACS - 10 Orbits; TRS - 100 Orbits - Orbiter - 100 Orbits	- Possible Cross Coupling Problems - Contamination with VCS - Pointing Disturbances
Inertia Balancing	- Continuous Pointing without Thrusters - Large Structure Secondary Objective - Can Reposition Orbiter to Circularize Momentum	- Weight Penalty: 20 to 40 K lb - Movable Structure - Flexible Body Dynamics

Figure 2.2-29 Solar Payload Accommodation for Apollo Telescope Mount Reuse

5) TDRSS Communications Contact Time, Shuttle-Tended Mode

During Shuttle tended operations, Skylab/payload data can be transmitted through the Orbiter system antennas to TDRSS. However, the Skylab attitude constraints, combined with shadowing or masking of the Orbiter antennas can reduce communications capability. An analysis was made to define the line-of-sight contact time to two satellites; TDRS east and west. The results, assuming use of two Orbiter antennas, are shown in Figure 2.2-30. The Phi angles on the figure are roll angles about the number 3 axis (see 2) above). These represent various cluster attitudes such as those needed for stellar viewing.

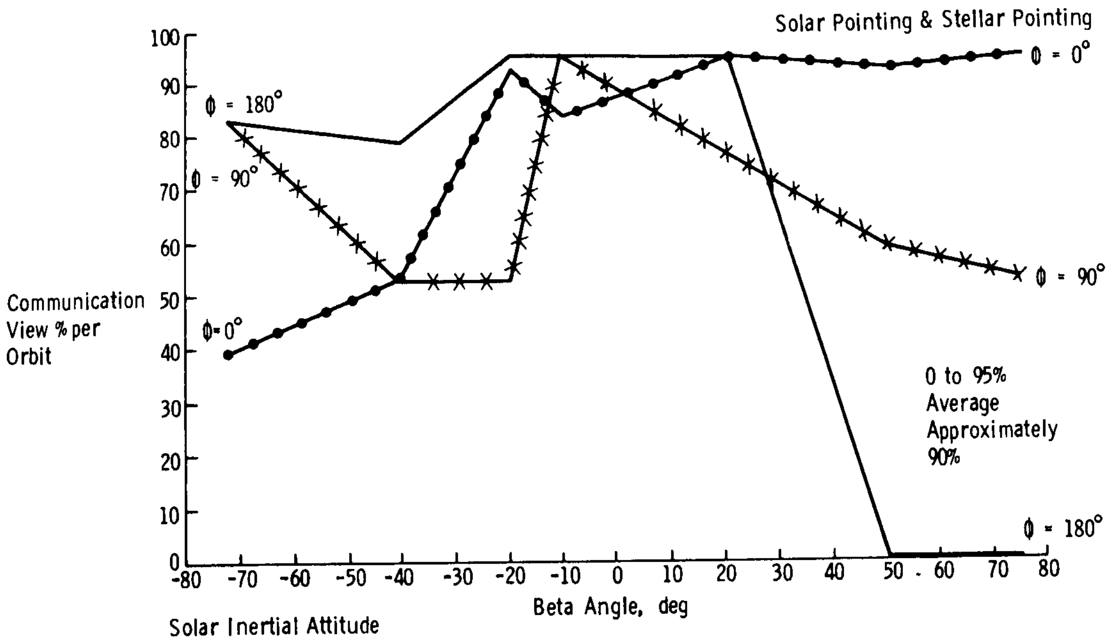


Figure 2.2-30 TDRSS Line-of-Sight Communications--Solar and Stellar Pointing

The figure shows that TDRSS communications are available for significant percentages of available time. However, data recording will be required for most viewing attitudes. Figure 2.2-31 shows the results of an analysis for the TDRS communications for an earth pointing payload.

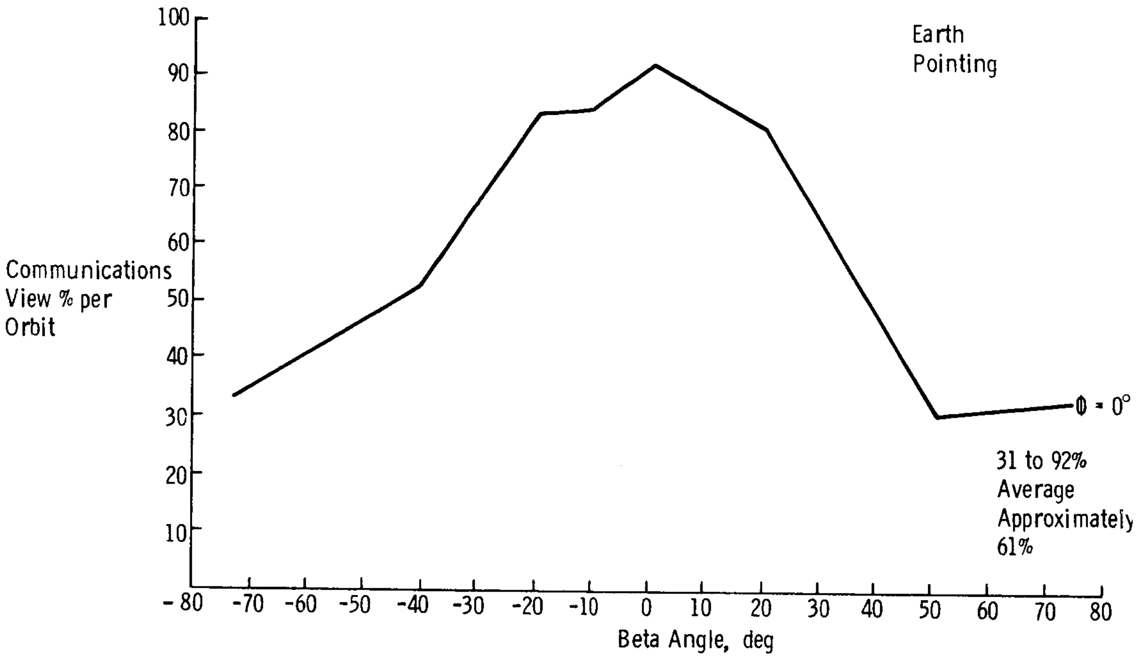


Figure 2.2-31 TDRSS Line of Sight Communications for Earth Pointing

6) **Power Requirements and Capabilities During Evolutionary Buildup Of Cluster, Tended and Untended Modes**

Power is provided to the cluster from several sources. During the refurbishment missions, the Orbiter and Skylab can separately provide their own power. This arrangement simplifies interfaces and should reduce costs. During Phase III (operation with the Shuttle attached), the Power Module and Skylab jointly provide power. Orbiter fuel cells operate only at a low rate, and power is transferred across the Interface Module to the Orbiter busses. Figure 2.2-32 shows the Skylab and Orbiter overhead power requirements, compares these to power available, and shows remaining power available for payloads. Orbiter power requirements are assumed as 11 kW, Skylab as 4 kW manned. Power available for payloads should be 7 to 11 kW, with higher levels available at high Beta angles when the cluster is in continuous sunlight. During Phase IV, when the Skylab operates without the Shuttle, an additional 11 kW is available for payloads.

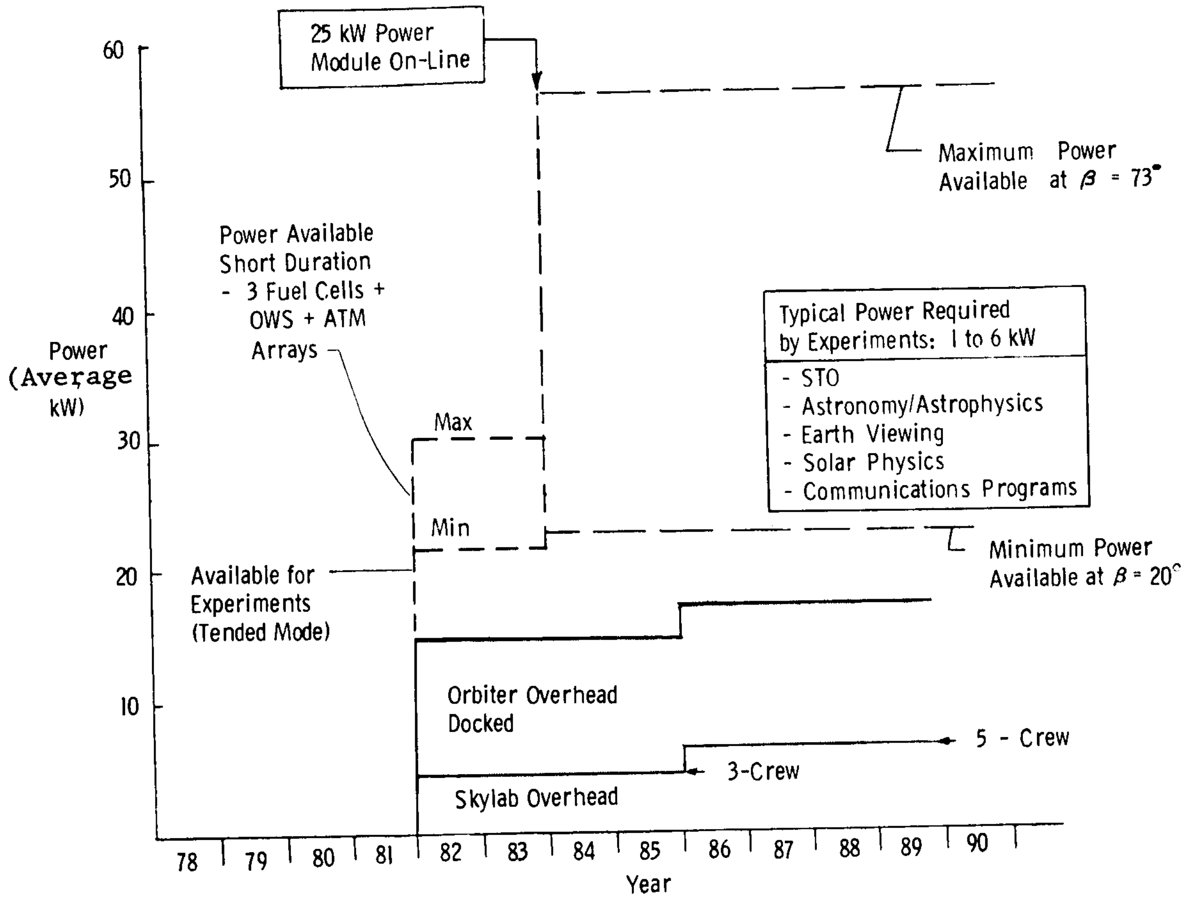


Figure 2.2-32 Power Requirements and Capabilities

7) Evaluation of Potential Reuse of Skylab Experiments

The Skylab configuration presently on orbit contains many articles of equipment for conducting scientific and engineering experiments. The utility of this equipment for further R&T reuse has been evaluated based on known inflight performance, status of equipment at shutdown, interrogation results to date, and engineering judgements of reuse values. This evaluation was aided by inputs from NASA personnel, principal investigators, and others who have knowledge of both Skylab and of future science and technology programs.

The four major categories of Skylab experiments considered for reuse are: the ATM, life science, materials processing, and earth resources. The ATM and life science experiments have excellent reuse potential, and are discussed in more detail in later paragraphs.

The materials processing and earth resource experiment package (EREP) appears to have little reuse potential. Generally, these instruments have become obsolete because of the large technological advancements made since 1973 in observation techniques by satellites, and the anticipated superior capabilities of instruments under development for Spacelab. It is possible, however, that the M518 Multipurpose Electric Furnace System could have future value as a high-vacuum research tool, and that the S190B Earth Terrain Camera could be useful in recording earth images to to complement data acquired with Spacelab-derived instruments.

Reuse of ATM Equipment

A highlight of Skylab Reuse, other than habitation, is the potential for data acquisition using the ATM instruments. Table 2.2-4 lists these instruments along with performance, status and restart information. These instruments have support from the science community for reuse because of their excellent quality, high resolution and proven performance with manned operations. Anomalies in the "status" column are not expected to degrade performance or operability to any significant degree. Further ground interrogations can provide telemetry data to enhance knowledge of their reuse or refurbishment requirements. When the vehicle is revisited, full operation of experiments can be checked by installing film

Table 2.2-4 ATM Experiments Reuse

Experiment	Performance	Status at Shutdown	Restart Requirements
S052 (ATM White Light Coronograph	Excellent	Operable.	Reload film.
S054 (ATM) X-Ray Spect.	Excellent	Door pinned open. Bent shutter blade. Operable.	Reload film.
S055A (ATM) UV Spectrometer	Excellent	Intermittent high voltage tripout. Door ramp latch removed. Operable.	
S056 (ATM) Dual X-Ray Telescope	Excellent	Filter 3 light leak. Door ramp latch removed. Operable.	Reload film.
S082A (ATM) XUV Coronal Spectroheliograph	Excellent	Door pinned open. Operable.	Reload film.
S082B (ATM) UV Spectrometer	Excellent	Doors disabled open by ground command. Low video signal level. Operable.	Reload film.
H-Alpha Telescopes	Excellent	Door pinned open. Operable.	Reload film.

and collecting data. The C&D console can also be exercised to furtner verify system operational integrity. With the addition of the S-Band communications to the Skylab, capability would exist for up-linking additional commands. These could be decoded and used to select specific ATM TV cameras (S052, S054, S082, H-alpha 1 or H-alpha 2). With cameras operating, there currently is TV down-link capability for one instrument at a time when the S-Band is installed. The design for modification to expand the number of instruments requires further study. Data from these instruments can complement solar physics and solar terrestrial programs.

Reuse of Life Science Equipment

The Skylab biomedical experiments are shown in Table 2.2-5. Some have potentially high reuse benefits. The M171 Ergometer (stationary bicycle) and the M092 Lower Body Negative Pressure Device (LBNP) are particularly beneficial for health monitoring and maintenance. These devices require large weight and volume accommodations of a space platform like Skylab. Other equipment has probable reuse, as the table indicates for general medical purposes. They exist on Skylab and are operable.

Table 2.2-5 Skylab Medical Experiments

Experiment	Status	Resupply	Reuse Potential
M071 Mineral Balance	Operable	Urine sample containers fecal collection bags	Low
M073 Bioassay of Bodily Fluids		Urine sample containers fecal collection bags	Low
M074 Specimen Mass Measurement		None required	High
M078 Bone Mineral Measurement		N/A	High
M092 Lower Body Negative Pressure		None required	High
M093 Vectorcardiogram		New harness electrodes may be required	High
M110 Hematology/Immunology		Automatic sample processor kit resupply required	Low
M131 Human Vestibular Function		None required	Low
M133 Sleep Monitoring		New monitoring caps	Low
M151 Time & Motion Study		35 MM film	Low
M171 Metabolic Activity		New mouth piece for metabolic analyzer may be required	High
M172 Body Measurement	Operable	None required	High
Inflight Medical Support System (IMSS)		Resupply of drugs and certain consumables e.g., batteries	High

Resupply consumables only: No hardware modifications/repair anticipated

The Inflight Medical Support System (IMSS) exists and is very useful, as it contains over 1300 different line items. The IMSS includes equipment, such as, air samples, incubator, slide stainer, and splints. It also includes a number of kits such as microscope, hematology/urinalysis, microbiology, I.V. fluids, drug, minor surgery, therapeutic, dental, diagnostic, and bandage kits. The crew had equipment and training to perform common surgical procedures, if required. This equipment was (and is) also available for contingency, nonmedical use. For example, the saw that was used to cut the solar panel loose on the first mission was a surgical saw from this kit.

In summary, the Skylab life science, biomedical equipment worked well and should be in good condition for reuse. As the Skylab program progresses, these capabilities can be upgraded by installing Spacelab-derived equipment, as ample room exists even for such large devices as the Spacelab vestibular sled.

8) Accommodations For Growth Add-On Experiments

Table 2.2-6 is an example of growth payloads which can be supported in Phase III (Shuttle tended operations), and continued in Phase IV (untended operations). These dedicated payloads are rather large and cover each of the scientific disciplines considered during the Skylab Reuse Era. Skylab will be extremely useful in developing engineering operational techniques for many of these payloads which may be constructed in orbit. For others, Skylab affords a unique habitable environment for long-duration dedicated experimentation.

Table 2.2-6 Examples of New Advanced Payload Concepts

Experiment Name	Discipline Area	Physical Characteristics	Power Required (kW)
30m Radiotelescope	STO-Stellar	30m Dish, 10,000kg	2
Long Dipole Antenna	STO-Stellar	1,000m, 100kg	1
Pinhole Camera	STO-Solar	20m Mask, 6,300kg	0.5
15m Parabolic Antenna	PSP-Communications	15m Dish, 2,700kg	20
15m Linear Phased Array	PSP-Navigation	15m Array, 25kg	2
100m Parabolic Antenna	PSP-Communications	100m Dish, 30,000kg	50
1.5-3.0m Optics	PSP-Resource Mapping	2,000kg	5
30m Thin Film Optics	PSP-Resource Mapping	500kg	1
Active Laser Radar	PSP-Resource Mapping	30m Antenna, 500kg	1
Real Aperture Side-Looking Radar	PSP-Resource Mapping	1,000m	1
Space Processing R&D	SPA	Spacelab-Type Dedicated Module	8
Life Sciences R&D	LS	Spacelab-Type Dedicated Module	4
150 kW Power Module	Solar Power	100m, 25,000kg	NA

The OWS forward compartment was used during the prior mission for experiment performance, ancillary equipment stowage, and subsystem hardware. The modified forward compartment shown in Figure 2.2-33 contains Spacelab racks for performance of space processing and life science experiments.

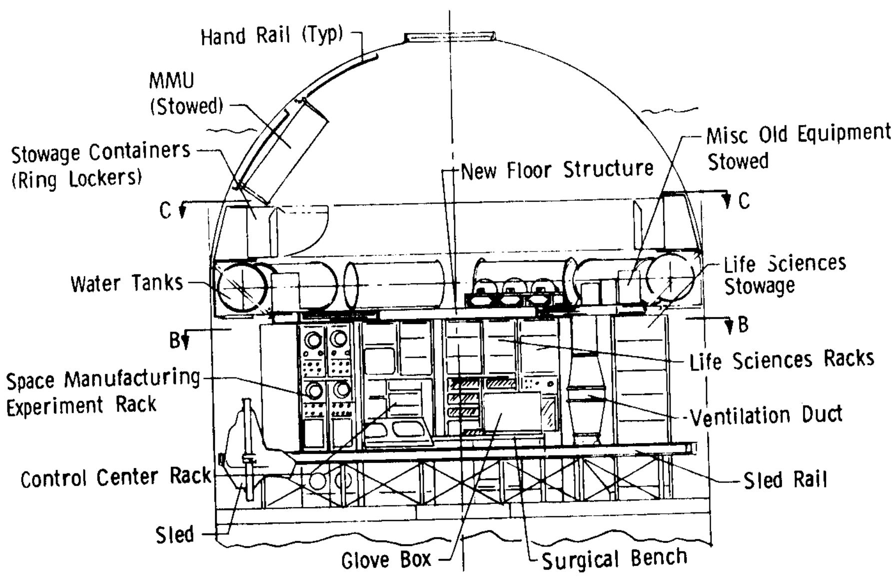


Figure 2.2-33 Spacelab-Derived Experiments Located in the OWS Upper Floor and Dome Area

Figure 2.2-34, a view of the floor in the forward compartment, shows various stowage containers remaining from the original Skylab with the new Spacelab provided science equipment, which can be used during Phases III and IV. This view also illustrates the scientific airlocks which may again be used for support of observing instruments.

By the installation of a new top floor in the workshop forward dome below the water tanks, equipment can be moved into this area from the forward compartment, attaching it to the new floor for storage and, thus, making room for the proposed Spacelab Experiment racks, in Figure 2.2-35.

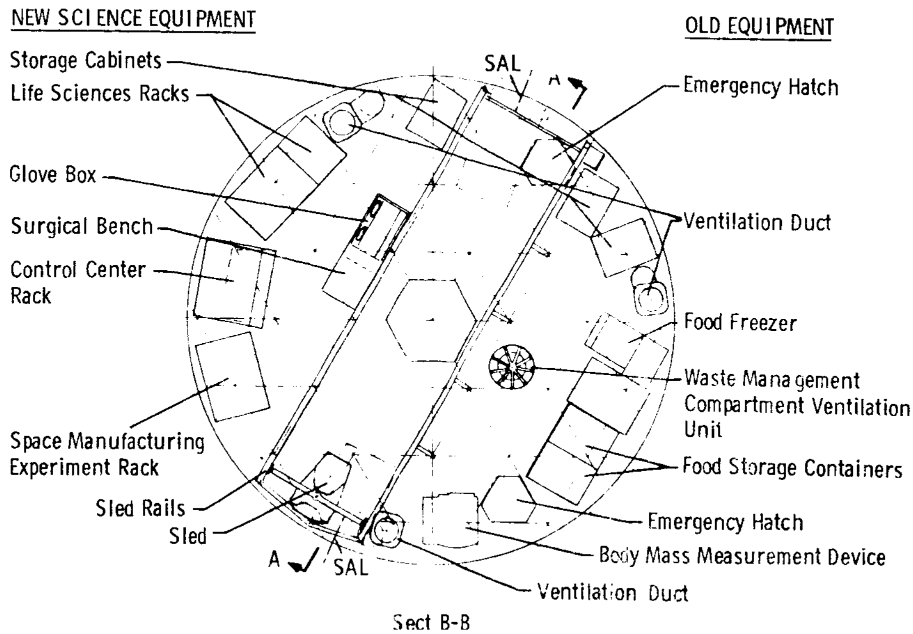


Figure 2.2-34 Spacelab-Derived Experiments Located in OWS--Upper Floor Arrangements

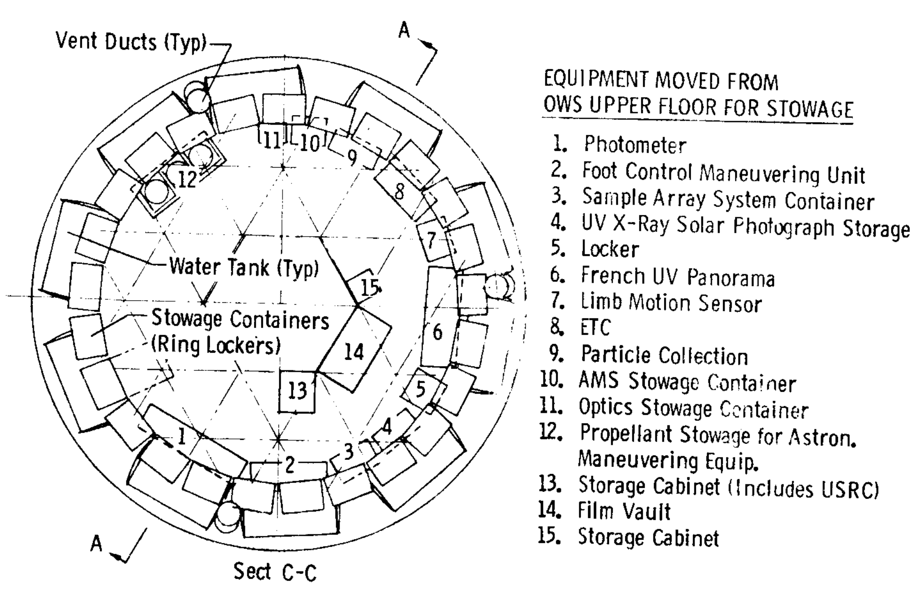


Figure 2.2-35 Spacelab-Derived Experiments Located in OWS--New Top Floor

Analyses of experiment requirements show important needs for space construction supporting such future programs as solar energy and communications. The Skylab complex can be used to develop and demonstrate space construction techniques. Two of the various concepts are illustrated in Figures 2.2-36 and 2.2-37. First, the Skylab can be used as a structural strongback for mounting equipment and as a base for the buildup of large structures. Alternatively, a Space Shuttle External Tank can be attached to the Skylab complex for use as a structural strongback, with Skylab providing habitation for the crew.

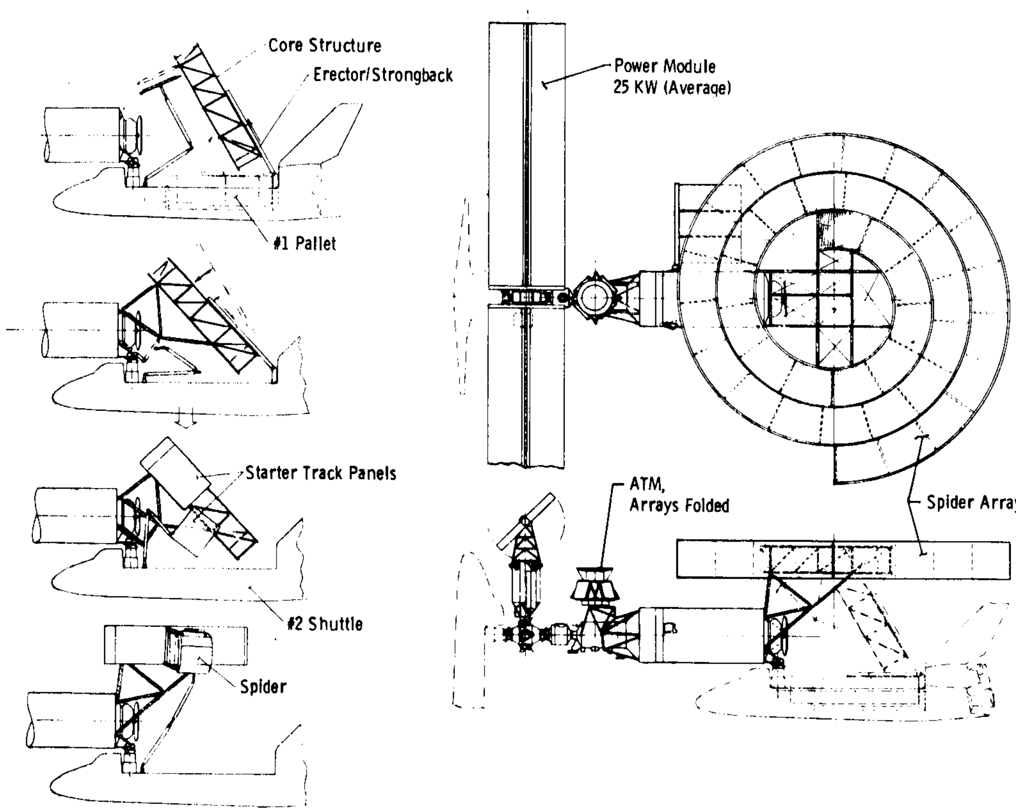


Figure 2.2-36 Solar Power Development with Skylab--Spider Array

Construction concepts for utilizing Skylab or the External Tank as strongbacks can be highlighted as follows:

Skylab as Strongback:

- Beam Building, Joining Experiments

- Space Crane/Cherrypicker Evaluation
- Construction of Power Collection and Transmission Demonstration and/or Large Communication Antennas

External Tank As Strongback Docked to Skylab Complex

- Skylab Used as Housing for Construction Crew of Seven
- External Tank Modified with RCS Modules and Forward Docking Mechanism (No Internal Modifications)

a) Solar Power Development With Skylab-Spider Array

Utilization of Skylab as a strongback is illustrated in Figure 2.2-36 showing the buildup of a large Space Spider solar collector array. The sequence on the left shows an auxilliary docking port for Shuttle attached to the aft Skylab skirt and the core structure assembled using Orbiter bay erector structure.

The right shows a finished array structure that generates approximately 45 to 50 kW average power. This type of construction will serve well as a development phase for larger free-flying space spider structures.

b) Solar Power Development With Skylab - Flat Array On ET

Figure 2.2-37 illustrates the Skylab complex with an External Tank (ET) being used as a construction strongback. Skylab provides habitation for the construction crew assembling a large flat array. It shows utilization of a beam builder and a space crane/cherrypicker to build and assemble the large space structure. Attachment fittings for assembly fixtures and beam builder, as well as rails and RCS modules for attitude control, are outfitted on the ET before launch.

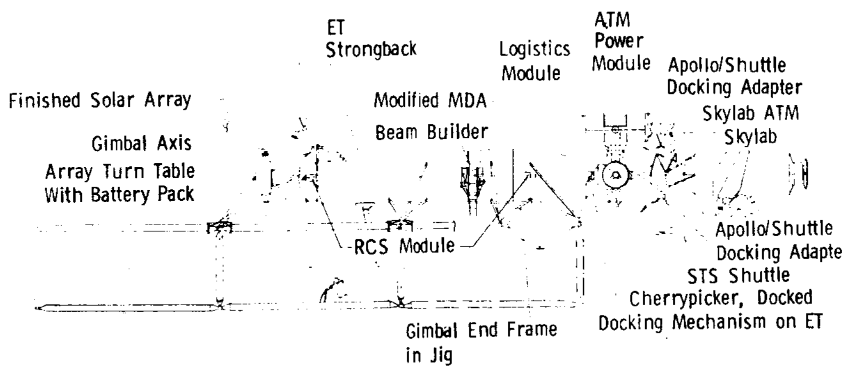


Figure 2.2-37 Solar Power Development with Skylab--Flat Array on ET

Assembly takes place sectionally, moving sections of the array panels aft as the buildup proceeds. Following completion, the finished solar array is rotated to an aft gimbal location for solar orientation.

Another concept of using Skylab as a strongback entails use of a pinhole camera to detect x-ray emissions from the sun, as shown in Figure 2.2-38. For resolving source locations accurately on the solar sphere, a large objective (pinhole mask) is situated one to 10 KM in front of the detector. Laser beams are used to position the detector and control its attitude accurately with respect to the mask.

This concept of using Skylab as a strongback on which to mount a pinhole mask, uses the Teleoperator (TRS) core as a platform for detector and subsystems required to control position and attitude and process data and communication.

The truss beams holding the pinhole mask in place can be built by a beam builder in the Shuttle Payload Bay or attached to Skylab. The mask itself would probably be a deployable structure.

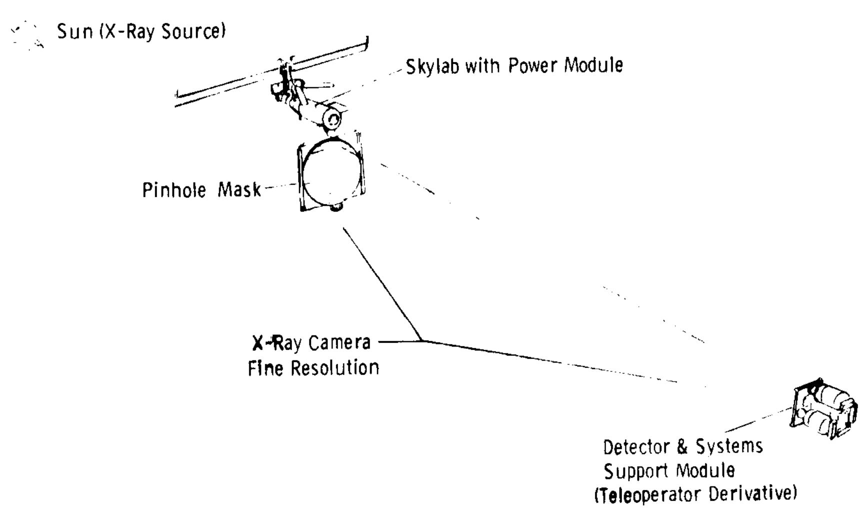


Figure 2.2-38 Representative Growth Payload--Pinhole Camera

9) Other Potential Skylab Reuse Opportunities

In the event that Skylab is not used as a habitable vehicle, a number of practical vehicle applications are possible. If the vehicle retains stability, a high potential use would be to reactivate the ATM instruments to complement observations with other solar payloads. The possibility also exists of adding small, low cost instruments such as a solar flux monitor and passive experiments. Spacelab derivative payloads, such as solar physics, solar terrestrial, or astrophysics, could be docked and operated from Skylab. However, these could also be operated from a free-flying power module. With the addition of a stabilized Interface Module, Skylab could be used as a dedicated STO, providing an instrument platform for years of solar/terrestrial experimentation. Skylab could also be used as an early stage base or strongback for large space structure technology.

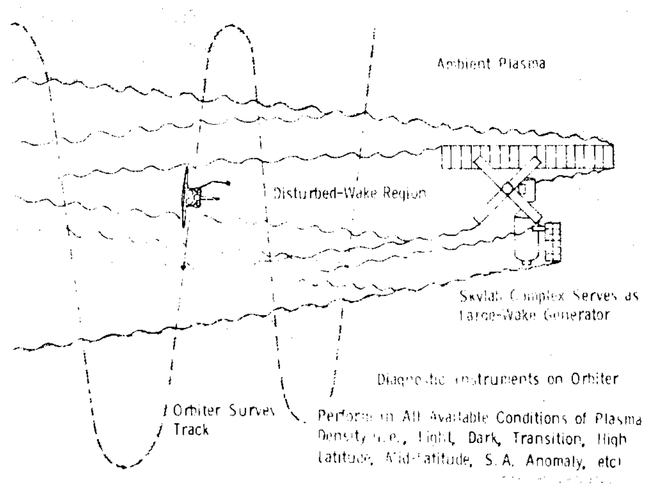
Experiments of a complementary nature with Space Shuttle scientific payloads could be flown using Skylab as a free-flyer. Measurements of the plasma wake created by Skylab (Figure 2.2-39) are typical experiments.

If the vehicle retains a gravity gradient orientation or has low rotational rates (within the capabilities of the Teleoperator Retrieval System, for example) low cost, long duration exposure experiments could be added, such as lexan sheets to record tracks of high energy particles. Samples of selected materials and parts could be exposed on the Skylab platform and later retrieved for evaluation of space environment effects by ground laboratories. Some recoverable items could be retrieved for their economic value for reflight purposes, such as high quality lenses, or with more difficulty, the optical window in the MDA.

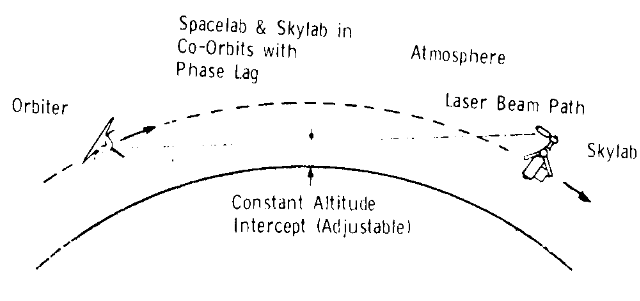
Using the Teleoperator Retrieval System to stabilize Skylab, early deployable mast structures can be attached and tested. An example is under study by Martin Marietta Aerospace for LaRC. Here a 1500-foot long astromast is deployed from Skylab and the structure excited to evaluate modes. This experiment can lead to others including attachment, joining, aligning, refueling and other functions needed to demonstrate technology developments for operational systems deployed in geosynchronous orbit.

Figure 2.2-39 shows other examples of complementary operations with Shuttle and Spacelab payloads. These all involve both Skylab and Spacelab payloads, but each vehicle is located at some distance from one another. The crew can perform cooperatively on both vehicles to operate various receive/transmit equipment and sensors. Other examples of cooperative experiments are chemical release observations, wave/particle coupling, plasma waves/instabilities, plasma transmissibility, and microwave power transmission.

Plasma Wake Studies



Laser Absorption Trace Constituents Survey



Orbiter & Skylab in same orbit with phase lag.
Intercept altitude adjustable by slight phase change.
Provides continuous data along orbit track at a given altitude.

Figure 2.2-39 Examples of Complementary Operations to Shuttle/Spacelab

10) Payload Accommodations Summary

Representative payloads defined in this study were evaluated for operation with Skylab/Shuttle/Power Module cluster resources. The analysis concentrated on the early (1984-1986) payloads and considered operation 1) from the cargo bay and 2) attached to the Interface Module. It was found that all payload disciplines can be accommodated on Skylab when both locations are considered.

Skylab was put in a 50 deg inclination orbit because of the broad experiment scope,such as earth viewing over most populated areas and magnetospheric viewing toward the north pole auroral region. Analysis of the inclination requirements for payloads in the STS traffic model (STS 560) shows that 70-80% of the Spacelab payloads are compatible with the Skylab orbit inclination.

Furthermore, a large percentage of science/technology objectives are enhanced significantly by mission durations of 30 to 90 days (or more). Based on data from the STS mission model and the Skylab reuse experiment requirements, it is estimated that 70% of payloads benefit from flights longer than 30-days and 50% of payloads benefit from flights longer than 50-days. Some payloads, such as STO, benefit from observations over much longer time spans. Again, these are compatible with Skylab capabilities.

More specifically, analyses of this study showed that non-pointed experiments such as life sciences and space processing are readily accommodated by Skylab, as are early construction type payloads, such as those relating to solar power or communication antenna fabrication/assembly. Pointing requirements to most star fields (10 of 11 evaluated) was found to be achievable for gimballed telescopes. Earth pointed instrument requirements can be accommodated with: 1) continuous nadir orientation at high Beta angles, 2) short duration passes such as those used for the earth resources experiment package (EREP) during the original Skylab program, and 3) instrument gimbals from an inertial orientation.

Solar pointed payloads can be accommodated by removal from the cargo bay and attachment to the Interface Module. Preliminary analysis shows that solar viewing from the cargo bay may be feasible, but additional thermal analysis is needed to find the allowable angles between solar vector and cargo bay.

The baseline power module can provide three primary resources for early payload operations: 1) power, 2) heat rejection, and 3) stability.

The power available for payloads from both Power Module and Skylab arrays is 7 to 11.4 kW at low beta angles when Shuttle tended and increases by the Orbiter overhead (11 kW in this case) when untended. This is sufficient to meet requirements of 5 to 7 kW for the Spacelab-derived experiments projected for the 1984-1986 period. The combined heat rejection capabilities of the Orbiter and Power Module radiators (equivalent 6.7 kW thermal rejection from the Power Module) also meet the requirements of the projected payloads. Attitudes where the sun line is perpendicular to the Orbiter bay should be avoided.

Attitude control can be maintained compatible with the pointing requirements of experiments using CMGs. For the configurations of the Skylab cluster that were studied, three CMGs (either in the Power Module or the Interface Module) can accommodate the basic control requirements.

Access to the TDRSS is needed for S-band and Ku-band communications. Line-of-sight to TDRSS satellites from Orbiter antennas is available for most orientations of the cluster. For operation in the untended mode, a Ku-band, high-gain system is needed. This system is mounted in the Interface Module with cabling to external, steerable antennas.

Further evolutionary growth of the Skylab cluster to meet new payload requirements beyond the 1985 period is feasible. These future needs can be accommodated by addition of modules, pallets, strongback fixtures, and equipment to the cluster. Interface module concepts with multiple docking ports can be used to attach new facilities to build the space platform science and technology capabilities, while Skylab continues to provide crew habitation functions.

3.0 ASSESSMENT OF SKYLAB FOR SYSTEM REACTIVATION

3.1 Assessment of Current Status and Requirements

3.1.1 General

The status of Skylab hardware and consumables has been tracked and assessed during the performance of this study contract. Continuous assessment of status has formed the basis for defining requirements for refurbishment kits and has had impact on operational contraints and recommended growth capability defined elsewhere in this report.

Information relating to Skylab status comes from several sources. Prior to the initial interrogations of Skylab in March 1978, the primary source was a review of existing 1974 Skylab flight data and flight operations documentation which yielded subsystem status and close-out configuration as of the final 1974 Skylab mission. This assessment was enhanced by the 1974 ASTP alternative mission study performed by Martin Marietta which evaluated all Skylab systems and subsystems. Further insight into Skylab's status and space system viability was established by the 1977 Martin Marietta/NASA in-house study, which concluded that Skylab could be successfully reactivated and that significant mission utility could be provided.

These preliminary conclusions were confirmed by the data obtained during the March, 1978 interrogations of Skylab and have been further strengthened by continuing operation and monitoring of Skylab Systems up to the present. By mid-August, 1978, no serious problems have been encountered negating the conclusions and recommendations of this study.

Table 3.1-1 and the following paragraphs relate the current status of each major Skylab subsystem and the corresponding assessment for reuse.

3.1.2 Structures Subsystem

Skylab structure was designed to an operational pressure of five-psi. Review of the Skylab A Strength Summary, 10M33111, indicates that pressure can be increased to 7.5 psi with adequate strength margins.

The structure of the Skylab Cluster is strong enough to handle the Orbiter/Power Module/Skylab cluster loads imposed by CMGs, Skylab TACS, or Orbiter RCS vernier thrusters used for cluster orientation and control. It is also adequate for Orbiter docking loads and TRS reboost loads. Table 3.1-2 summarizes these loads vs. Skylab capability.

Table 3.1-1 Summary of Systems/Subsystems Status

Subsystem	Status (September 1978)	Remarks
Structures	Internal pressure 1974=1.2 psi; leaked to zero. Presently maintained at 0.15 to 0.35 psi. Leakage extrapolates near spec rates.	Pressure shell accommodates 7.66 psi at S.F. = 1.4
Electrical Power (EPS)	AM System good--7 of 8 Batteries/Chargers Operable ATM System--9 of 18 CBRMs Operable	Batteries--5,500 cycles, good for 20,000 cycles (32 30-day mission). Solar array degradation $<10\%$.
Command/ Telemetry and Communications	All major components operable (one DC-DC converter out).	Early operations use ground station with UHF/VHF. 1980-1984 use Ku Band to TDRSS (tended) or S-band to GSTDN (untended); After 1984, use Ku Band to TDRSS.
Attitude Pointing and Control	TACS propellant remaining: 8,562 lb-sec; computer working; CMGs: Two operational, one failed.	Interrogation tests verify system operational. Need control software.
ECS/Thermal System	1045 kg (2300 lb) O_2 and 250 kg (550 lb) N_2 remain; coolant loops OK; AM coolant loop leaking as it was during mission; internal temperatures reasonable.	ECS working during interrogation; need coolant loop servicing capability; new sun shield required to accommodate all payload pointing attitudes.
Crew Systems	Operable for 3-man crew	Need resupply of crew consumables. Test, condition, resupply water. JSC white paper shows no biomedical effects preventing Skylab reactivation.

Table 3.1-2 Structures Status Summary

Skylab Cluster External Loads

Condition	Load	Skylab Capability*	Margin of Safety (Ult)
TRS Reboost	P = 1200 Lb	P = 27,500 Lb	High
Orbiter Docking	P = 975 Lb	P = 27,500 Lb	High
CMG Torque (5)	T = 600 Ft-Lb	T = 42,400 Ft Lb	High
Skylab TACS Torque	T = 6927 Ft-Lb	T = 42,400 Ft-Lb	3.37
Orbiter RCS Vernier Thrusters	T = 3343 Ft-Lb	T = 42,400 Ft-Lb	High

* Based on OWS-SAS beam fairing hinge capability (fairing hinge was determined by stress analysis to be critical load point, described in an Evolutionary Approach for an Affordable National Space Platform, 8/77, Status Report).

Any meteoroid penetrations need to be sealed to prevent leakage. Skin stress re-distribution will handle the local penetration area, but rough irregular holes should be smoothed to prevent crack propagation.

An analysis of material degradation was performed based on an eight year exposure of the Skylab OWS skin. The external temperature variation from + 110^{o}F to +448^{o}F with a time at temperature variation simular to that shown in An Evolutionary Approach For An Affordable National Space Platform, 8/77, Status Report was used for analysis. The 2219 aluminum skin of the OWS will have a permanent degradation of 27% in the eight year exposure at the described temperature variations. Since it was designed to 26 psia for ascent loads, the factor of safety is still high at habitation pressures of 7.5 psia.

The pressure shell leaked to zero as of the March 1978 interrogation, and is presently being maintained at 0.15 to 0.35 psi. It is currently leaking about 10 lbs/day extrapolated to a 5 psi pressure as compared to approximately 3 lbs/day during the mission. The current leakage rate is close to the levels specified by the Cluster Requirements Specification, RS003400003, 8/69.

In assessing structural capability for a 7.5 psia habitation pressure, design and proof pressures for the Skylab MDA structure were examined. Evaluation of the 12.4 paid burst pressure test results indicate that the actual burst factor above 7.5 psia would be 2.33 and the proof factor over 7.5 psia would exceed

1.5. The conclusion based on these static test safety margins is that the MDA could be pressurized to 7.3 psia eliminating the prebreathing requirement between Orbiter and Skylab, as illustrated on earlier Figure 2.1-8.

Although there apparently has been no meteroid penetration of the structure, meteroid analysis predicts two small holes by 1983. We have therefore included a patch and seal kit in the recommended refurbishment kit complement.

All data indicate the basic integrity of the Skylab structure is intact, and no constraints imposed on a Skylab reuse mission from the stand point of the structures subsystem.

3.1.3 Electrical Power Subsystem (EPS)

The Skylab Electrical Power System is comprised of 8 power conditioning groups (PCG's) on the Airlock Module fed by the solar array wing on the OWS, and 18 charger/battery/regulator modules fed by four solar array wings on the ATM. The initial March 1978 interrogations confirmed the integrity of many elements of Skylab EPS. At that time 7 of 8 PCGs and 15 of 18 CBRMS were operational. As of mid-August, 1978 the AM EPS continues to have 7 or 8 PCGs operational. The ATM EPS has degraded since March, with 9 of 18 CBRMs now operational. The principal failure mode has been that several of the 18 solar array groups have shorted thus denying a portion of power to Skylab.

Data obtained on the EPS indicate the array degradation is much better than expected, at less than 10% degradation. The EPS in its present condition has been supplying between 4 and 5 kW average power in solar inertial orientation of Beta = 0 degrees. For the highest Beta angle of approximately 73°, the average power should be between 9 and 10 kW. These actual power capability figures are very close to those used in assessing the capabilities and constraints of various mission profiles and configurations.

As of mid-August 1978, the Skylab batteries had accumulated approximately 6000 charge/discharge cycles, including 3790 up to the end of SL-4 and the remainder since the March 1978 interrogations. They will continue to accumulate at the rate of 16 cycles per day as long as Skylab continues to operate in its present mode. Nickel Cadmium batteries are typically good for 20,000 or more cycles at the depth-of-discharge experienced on Skylab, and they should have considerable life left in them for a Skylab revisit. For example, the 14,000 cycles remaining at the present time equates to approximately thirty 30-day missions. However, for extended use into the late 1980's, the possibility of replacing the Skylab batteries should be considered.

In terms of refurbishment kit requirements for the near term, the capability to transfer power from the Power Module to Skylab must be provided to supplement Skylab generation capability. This kit is discussed in Section 3.2.

3.1.4 Command/Telemetry and Communications Subsystems

The March 1978 interrogation of Skylab verified the integrity of command and telemetry subsystems. All major components except one dc-dc converter are operational and most instrumentation is good. These systems should continue supporting the interrogation activities and future missions. The audio and television subsystems have not been checked out and no verification of status is possible until a revisit occurs, but they were performing properly at the end of the Skylab mission.

Future applications of Skylab will require modifications to the communications systems in order to be compatible with the Orbiter and to provide data rates necessary for payloads. The recommended upgrading in this area is discussed in detail in Section 3.2.

3.1.5 Attitude Pointing and Control Subsystem

All basic elements of the Skylab APCS have been verified as operational by the Skylab interrogation tests of March through mid-August 1978. The system has successfully maneuvered Skylab from the March gravity gradient mode to a solar inertial attitude and End-on Velocity Vector (EOVV) attitude to present a minimum drag profile. Two of three CMGs continue to work properly. The Thruster Attitude Control System (TACS) propellant reserve has been reduced from 22,000 lb-sec in March to approximately 8,562 lb-sec in mid-August. Approximately 5,000 lb-sec is considered to be useable. This should present no problem for future Skylab interrogation operations as any planned maneuvers can be accomplished with the CMGs without further use of TACS. However for Skylab Reuse missions, TACS is required and the TACS propellant must be resupplied. A kit to accomplish this is included in the recommended list of refurbishment kits, and is discussed in detail in Section 3.2.

An analysis of combining the Skylab/Power Module/Interface Module/Orbiter cluster control system was performed. The result of that analysis follows.

The proposed control system is based on the premise that the PM maintains control when present, and that the Skylab control system will be in control when the PM is not present. In both cases, however, the Orbiter must always be capable of assuming control.

The present Skylab CMGs were assumed to be non-operational after the reboost mission because they would have far exceeded their design life at that time. Replacement of these CMGs was ruled out because of the extreme difficulties of the EVA operations.

The ATMDC will be used to perform all functions required during the initial Skylab Reuse missions. (Power Module not present). When the Power Module NSSC II Computer is in command, the ATMDC/WCIU will act as an interface, passing commands and signals to and from the TACS and the optional interface module mounted CMGs.

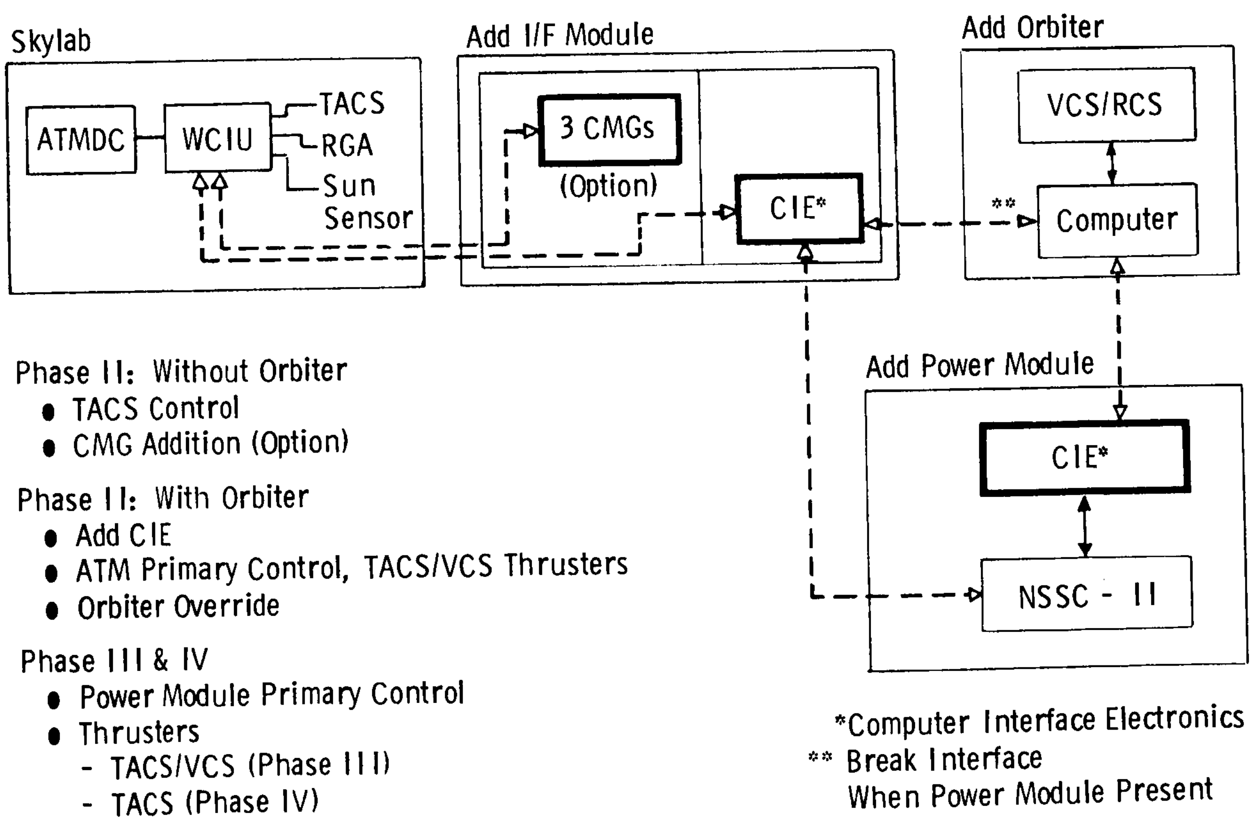


Figure 3.1-1 Combined Attitude Control System Concept and Evolution

Figure 3.1-1 shows the control concept of how the Skylab/Interface module will interface with the Power Module, Orbiter or both.

When the configuration consists only of Skylab and IM, the Skylab control system will function as it did during the Skylab mission except that the CMGs (if used) will be on the IM, and the CMG control law will be different.

When either the PM or Orbiter is added to the cluster, the ATMDC/WCIU will be required to communicate with the other onboard computer. Computer interface electronics are required to make the computers compatible. However, the interface electronics between the PM and Orbiter is an existing item, thus requiring no PM design impact. Table 3.1-3 lists the hardware components of the control system for the four possible cluster configurations.

Table 3.1-3 Controlling Hardware for Various Cluster Configurations

CMG Option ↓	Control System Hardware ↓ / Cluster Configuration →	Skylab IM	Skylab IM Orbiter	Skylab IM Orbiter PM	Skylab IM PM
No CMGs Added To Interface Module	Computer (Primary Control)	ATMDC	ATMDC	NSSC II	NSSC II
	Rate Gyros	Skylab	Skylab	PM	PM
	Sun Sensors	Skylab	Skylab	PM	PM
	Primary Actuator	TACS	TACS/VCS*	PM CMGS	PM CMGS
	Additional H Capability	No	No	No	No
	Thrusters	TACS	TACS/VCS*	TACS/VCS	TACS
3 CMGs (Optional) Added To Interface Module	Computer (Primary Control)	ATMDC	ATMDC	NSSC II	NSSC II
	Rate Gyros	Skylab	Skylab	PM	PM
	Sun Sensors	Skylab	Skylab	PM	PM
	Primary Actuator	IM CMGs	IM CMGs*	PM CMGs	PM CMGs
	Additional H Capability **	No	No	IM CMGs	IM CMGs
	Thrusters	TACS	TACS/VCS*	TACS/VCS	TACS

Impact due to 3 CMGs being added to interface module

* During refurb mission, orbiter VCS will be only control available

** H = Angular momentum

It is noted that if three CMGs are added to the Interface Module, CMG control is available when the Power Module is absent, which contributes significantly to fine-pointing and mission longevity.

3.1.6 ECS/Thermal Systems

The basic integrity of the ECS/Thermal System has been verified by initial Skylab interrogation and subsequent operations. The primary AM coolant loop continues to exhibit symptoms of the leak experienced during the mission, but there should be no degradation of performance in the immediate future. A small amount of O_2/N_2 has been used in repressurizing and maintaining pressure in Skylab. During the March, 1978 interrogation, 1136 Kg (2500 lb) O_2 and 273 Kg (600 lb) of N_2 remained, and by mid-August, 1978 1045 Kg (2300 lb) O_2 and 250 Kg (550 lb) N_2 remain. This amount of O_2/N_2 remaining is equivalent to six repressurizations or 560 man days. O_2/N_2 will require resupply less than one year after reactivation. This assumes two repressurizations during interrogations tests, and one for each of two missions with three-man crew for 30-days. Refurbishment kits for resupplying coolant to the AM coolant loops and for resupplying O_2/N_2 have been identified and are described in Sections 3.2.3 and 3.2.10.

Figure 3.1-2 maps internal and external temperatures based on analyses of July 1974 data with the March 1978 interrogation

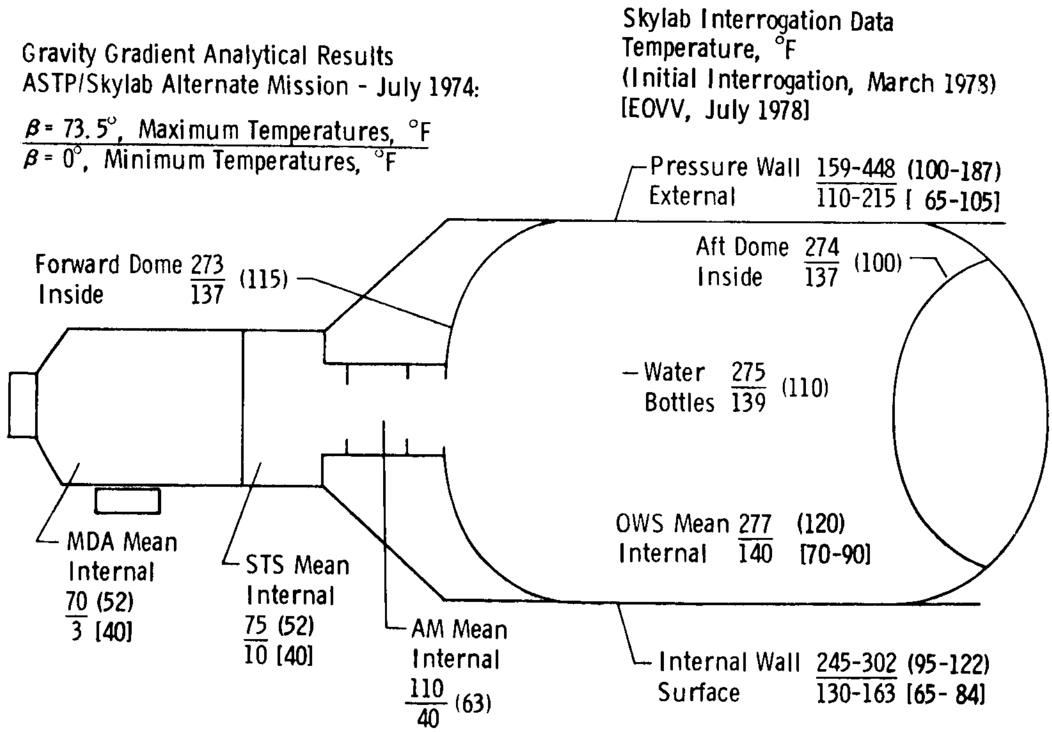


Figure 3.1-2 Skylab Internal Temperatures

in parenthesis, and data from July 1978 in the EOVV orientation shown in brackets.

Computations performed during 1974 for the ASTP/Skylab alternate mission showed wider limits than the values received via telemetry during the March through July 1978 tests. These calculations were run for Beta angles from 0^{o} to 73.5^{o}.

The conclusions drawn from this temperature profile are 1) the thermal characteristics of the external surfaces are basically intact and 2) the OWS sun shield is in place and performing properly. For future missions requiring various pointing attitudes, a wrap-around sun shield will be required. The refurbishment kit to supply this thermal protection is described in Section 3.2.5.

An investigation of Skylab internal materials thermal characteristics was performed (Table 3.1-4). As shown on the table, internal materials are compatible with the predicted and actual Skylab temperatures shown above in Figure 3.1-2.

Table 3.1-4 Skylab Internal Materials Thermal Characteristics

Item	Maximum Design Temperature, °F	Maximum Service Temperature, °F	Remarks
Insulation, Polyurethane Foam	275	400 to 450	Outgasses above Cure Temperature (300°F); chars above 450°F
Paints, Organic	300	>300	Outgasses, Cracks, Blisters
Nylon	250 to 300	>300	Softens, Outgasses, Decomposes
Neoprene	240	>250	Softens, Outgasses, Decomposes
Teflon	750	>750	Softens, Outgasses, Decomposes
Viton	300	300 to 350	Softens, Outgasses, Decomposes

3.1.7 Crew Systems

Skylab offers many advantages from a habitability and crew systems standpoint. An exceptionally large habitable volume is available and can be reused. Wardroom, waste management, and sleep compartments are sufficient for a three-man crew. Larger crews can be accommodated by time sharing, staggering shifts, and adding modifications. Sleep provisions will require resupply of items such as thermal backs, comfort restraints, top blankets, bottom blankets, pillow inserts, pillow covers, and body belts. For larger crews, additional sleep stations can be added.

Freezers and refrigerators are available for food storage. Resupply of food, beverages, and eating utensils is required. Also, resupply of frozen food is highly desirable,if the system is operable. Food facilities can also be augmented by installing an orbiter food galley. Food requirements are approximately 0.6 lb/man/day of frozen food and 5 lb/man/day ambient food.

There is presently 1175 Kg (2590 lbs) of water onboard;(875 Kg (1930 lbs) is usable). Its potability is unknown, but should be okay. The refurbishment kit for water resupply described in Section 3.2.7 includes provisions for testing and conditioning the water as required. Resupply of cation cartridge and personal drinking spouts is also required.

The waste management systems fecal/urine collector should be operable, but will require refurbishment of ancillary equipment, such as receiver cuffs and hoses, urine separator, fecal collector filter hose, collection bag, and urine dump heater probe assembly. These items are included in the waste management refurbishment kit described in Section 3.2.9.

Personal hygiene facilities should be operable, including shower. Resupply of expendables such as tissues and wipes, towels, wash clothes, soap, hygiene kits, squeezer bags and towel holders is required. Housekeeping items are partially available on-board in stowage, but some resupply is required.

The stowage facilities are reusable with some lockers presently empty, and some full with both usable and unusable items. It is recommended that more restraints on lockers be provided for lists and equipment holding. Mobility aids and restraints are usable, with resupply of triangle shoes and small parts restraint system required.

In summary, it is evident that the Skylab orbital assembly provides unique habitability provisions for long duration space flight. Figure 3.1-3 illustrates highlights of the available resources on Skylab.

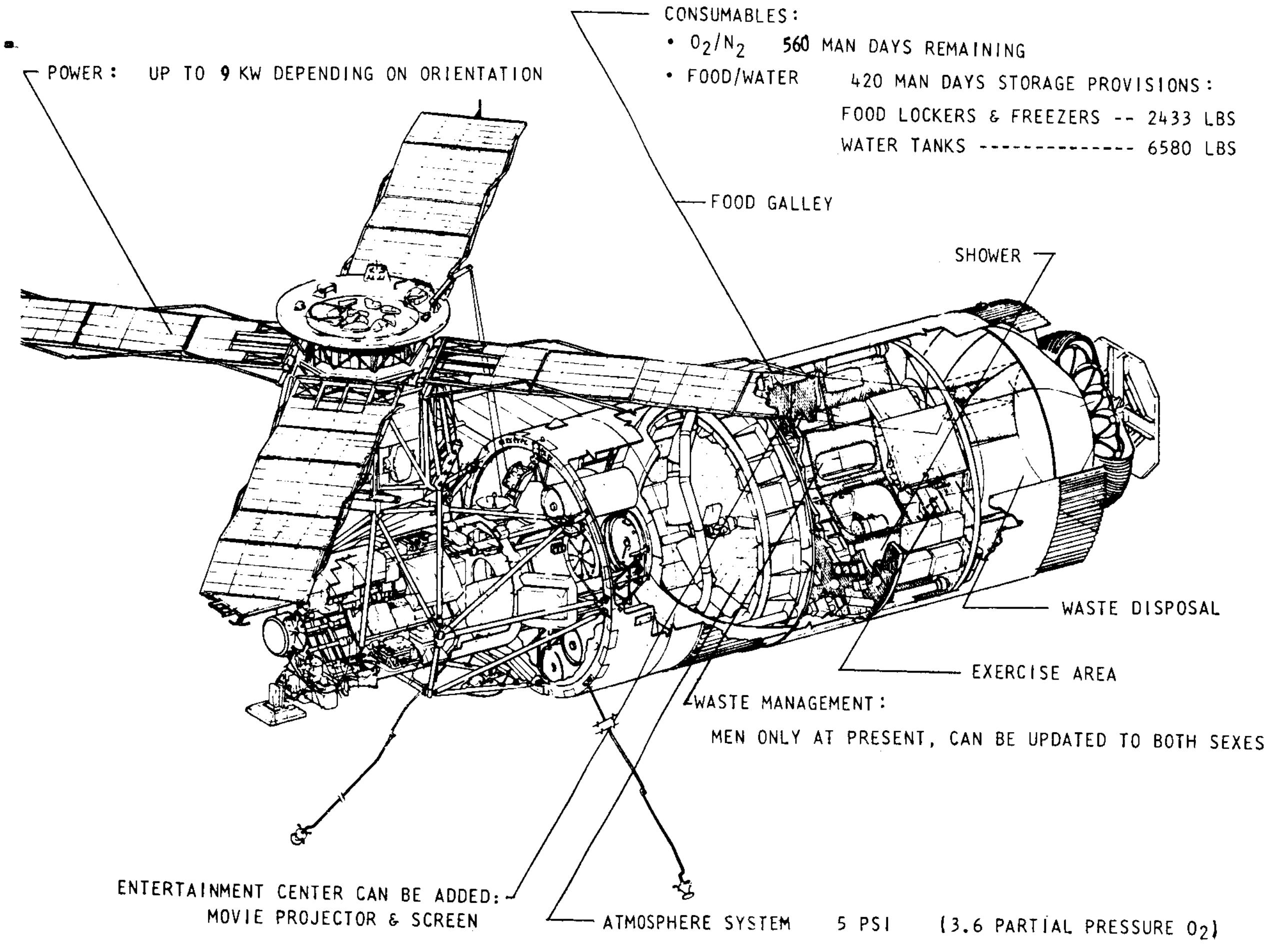


Figure 3.1-3 Skylab Habitability Provisions

3.1.8 System Analysis/SE&I

System analysis and System Engineering and Integration tasks for Skylab Reuse were compiled using the original Skylab job output list (JOL) as a basis. Tasks were deleted or added as required to fit the Skylab Reuse Program. The following System Analysis/SE&I tasks form the basis of system engineering effort costed in Section 5 of this report.

1. Cluster System/Subsystem Analysis

Thermal Control System (TCS)

Combined cluster masking and sun shield effects
Use existing thermal computer models (TRASYS and MITAS)

Environmental Control System (ECS)

Combined Shuttle/Interface Module/Power Module/Skylab ECS evaluation, including airlock effects

Modify and use existing ECS computer model

Mechanical/Structural/Dynamics

Docking and re-orientation loads and responses
Vibration modal analysis
Strength summary
Payload boost flight analysis
Use existing structural/dynamics computer models (PFINEL)

Electrical Power System (EPS)

Power balance and cross-feed between elements

Power capabilities at various cluster attitudes

Update SEPSA (computer model) input data file

Instrumentation and Communications/Caution and Warning

Cluster communication interfaces

RF contact time predictions (command telementry coverage

Antenna contour plots

Use existing computer models (COCOA)

Attitude and Pointing Control System

Combined cluster pointing and maneuvering capabilities

Ground operations diagnostic procedures

Error budget analysis

Modify and use existing computer models (APCS Simulation Programs)

2. Test Integration

    Cluster On-Orbit Test and Checkout Requirements and Procedures

        Subsystems

        Refurbishment kits

        Interface Module

3. Mission Operations Analysis

    Ground Operations Planning Requirements

    Change Operational Data Books and Related Documents

    Establish Mission Rules

4. Systems Engineering

    Mission Planning Analysis

    Crew Systems/Stowage/Inflight Plus Maintenance (IFM)

    Reliability/Safety/FMEA

    GSE/Logistics/Facilities

    Contamination

    Mission Evaluation

    System Definition & Analysis

    Trade Studies

5. Experiment Integration

    Phase III Payload Compatibility Analysis

3.2 Refurbishment Kits

3.2.1 Summary

Equipment defined for reactivation and update of Skylab is shown in Table 3.2-1, including need dates. The kits represent known equipment with no new technology required. Some kits are contingency items while others are for refurbishment/resupply (or update of communications for compatibility with the Shuttle).

Table 3.2-1 Refurbishment Kits

Kit	Description	Approx Need Date
Patch & Seal●	Seals, Sealant, Leak Detector	1982
Lighting●	Portable Lights, Spare Bulbs during Refurb	1982 (GFE)
Coolant Loop Servicing♦	Repairs, Recharges AM/MDA Loop	Use on Board System 1982
Communications▲	Intercom Link Among Crew during Refurb	1982
Air Circulation●	Blowers	Use On Board Spares 1982
Sun Shield▲	Wrap-Around Thermal Shield	Phase III
Power Transfer▲	I/F through MDA & ATM	1983
Potable Water♦	Test, Condition, Resupply Water	Test 1982, Resupply 1983-84
Food Preparation▲	Add Shuttle Food Galley, Standardize Food	Phase III
Waste Management▲	Replace Some Components, Adapt for Female	Test 1982, Refurb 1983
O_2/N_2 Recharge♦	Resupply O_2/N_2 Tanks on AM	Manifold 1982, Supply (Leak Dependent) 1983
Array Folding▲	Tools to Fold ATM Array	Test 1983, Fold Arrays PM Delivery - 1984
Attitude Control♦	Resupply TACS GN_2	Add Fill Tubing 1982, Fill 1982-1984
●Contingency Items	♦Refurb/Resupply	▲Update

Figures 3.2-1 through 3.2-5 summarize the refurbishment kits. Kits are defined based on, 1) subsystem information from on-going Skylab interrogations supplemented by end of mission data and recent analysis, 2) contingency equipment, e.g., portable lights, and 3) equipment for system expansion and update, e.g., additional crew quarters and food galley provisions. Based on knowledge to date, few systems require repair. Kits are primarily related to resupplying consumables. As seen on the figures, no new technology is required. Two of the kits (lighting and air circulation) are considered GFE items. No costs are estimated in Section 5.3 for these.

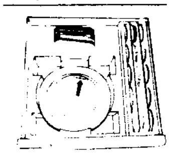
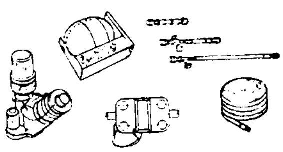
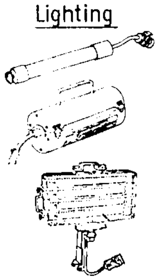
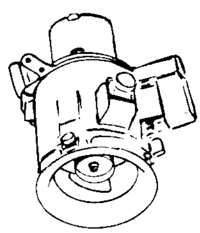
Kit	Description	Kit	Description
Patch & Seal Kit 	- Kit Similar to Skylab; New O Rings & Seals; - Leak Detector Required	Coolant Loop Servicing 	- Use Onboard Unit - Return For Refill
Lighting 	- Use Skylab/Shuttle Portable Lights; Obtain Replacement Bulbs As Contingency for Refurb Flights. - Test Onboard System for 1st Refurb Flight (1982) - Repair As Required for 2nd Flight - Note: Spare Lights on Board.	Air Circulation 	- Use Onboard Spares

Figure 3.2-1 Refurbishment/Update Kits for Skylab Reuse

Resupply of O_2 and N_2 for breathing and and Thruster Attitude Control System (TACS) is shown in Figure 3.2-2. We recommend at least partial TACS recharge when the kit is installed. Waste management repairs are not extensive. Adaptation for female use should be straight forward. The ATM array can be retracted using a simple plier type tool.

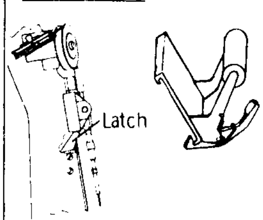
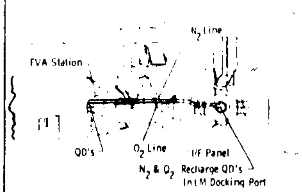
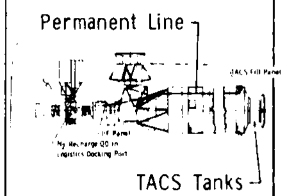
Kit	Description	Kit	Description
Waste Management Update, Resupply Skylab WMS - Female Use - Reduced Biomed Sampling	- Replace Separators/ Drawers With GFE Spares; Refurb 3 Drawers/9 Separators; Return to Inventory - Provide Male/Female Urine Cuffs	Array Folding 	- Simple tool to release latch - Motor drive to retract (manual backup) - Secure - May redeploy depending on payload viewing requirements, PM Envelope
O_2/N_2 Recharge: AM 	- Manifold O_2 and N_2 Tanks - Bring line to supply point on Interface Module	Attitude Control: TACS Resupply 	- Provide Line from Interface Module to TACS Supply Point - Resupply on first refurb flight

Figure 3.2-2 Gas Resupply Waste Management and Array Folding Kits

A sun shield (to replace the existing parasol) is shown in Figure 3.2-3. This kit is not needed until operation in attitudes greatly differ from the original solar inertial orientation is desired, such as full sky viewing, probably mid 1984. The water resupply kit connects the resupply point in the Interface Module to the ten tanks in the OWS. Power transfer consists of cabling between the Power Module and the ATM and MDA connectors on Skylab. Food preparation is an option for Phase III which allows standardization of Skylab and Shuttle food preparation.

Figure 3.2-4 defines the approach to extending television and intercom from Skylab to the Orbiter. However, intercom and television require installation of additional Skylab hardware in the Interface Module. These hardware items include intercom panels, a television input station (TVIS), and coax relays. The TVIS was incorporated into the Interface Module in a manner similar to the philosophy of the original Skylab, which had a TVIS in the CM.

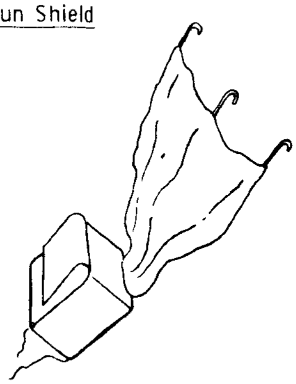
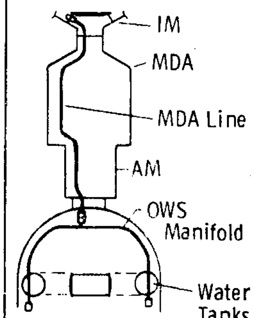
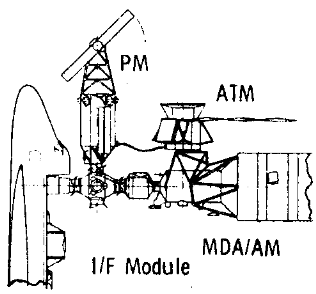
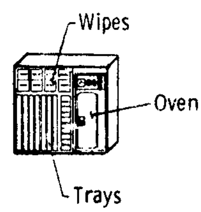
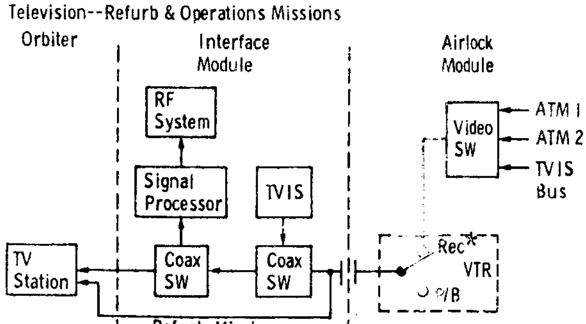
Kit	Description	Kit	Description
Sun Shield 	- 360° Coverage Needed For Stellar Orientations - Use Parachute Pack Type Soft Cover	Potable Water Test, Condition, Resupply Water 	- Install Resupply Manifold From Interface Module To Tank Area - Sample, Test Water
Power Transfer Cabling to Transfer Power to/from Skylab and Orbiter, Power Module. 	- Cabling From Power Module To ATM And MDA	Food Preparation 	- Shuttle Oven & Tray System - Option For Phase III

Figure 3.2-3 Sun Shield, Water, Power Transfer, and Food Preparation Kits

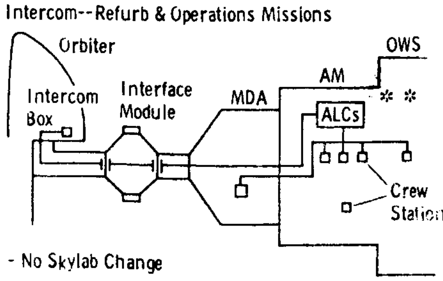
Television--Refurb & Operations Missions



- No Skylab Change

* Video Tape Recorder

Intercom--Refurb & Operations Missions



- No Skylab Change

** Audio Load Compensator

Figure 3.2-4 Television and Intercom Kit

The link to ground during Shuttle tended periods uses Orbiter TDRSS communications. Equipment is installed in the Interface Module to make the data compatible with the Orbiter System. An S-Band System (from the Command and Service Module System used on Skylab) is provided which makes the Skylab communications compatible with STDN and allows transmission of ATM video data. The CSM S-Band System can be incorporated into the Interface Module. Optionally, if the Power Module is available, Skylab communications system could directly interface to the Power Module and the CSM System would not be required, but some data interleaving and compression modifications would be necessary. Figure 3.2-5 shows the communications concept. A Ku-Band System can be added later to the Cluster, allowing autonomous Skylab operation untended by the Orbiter.

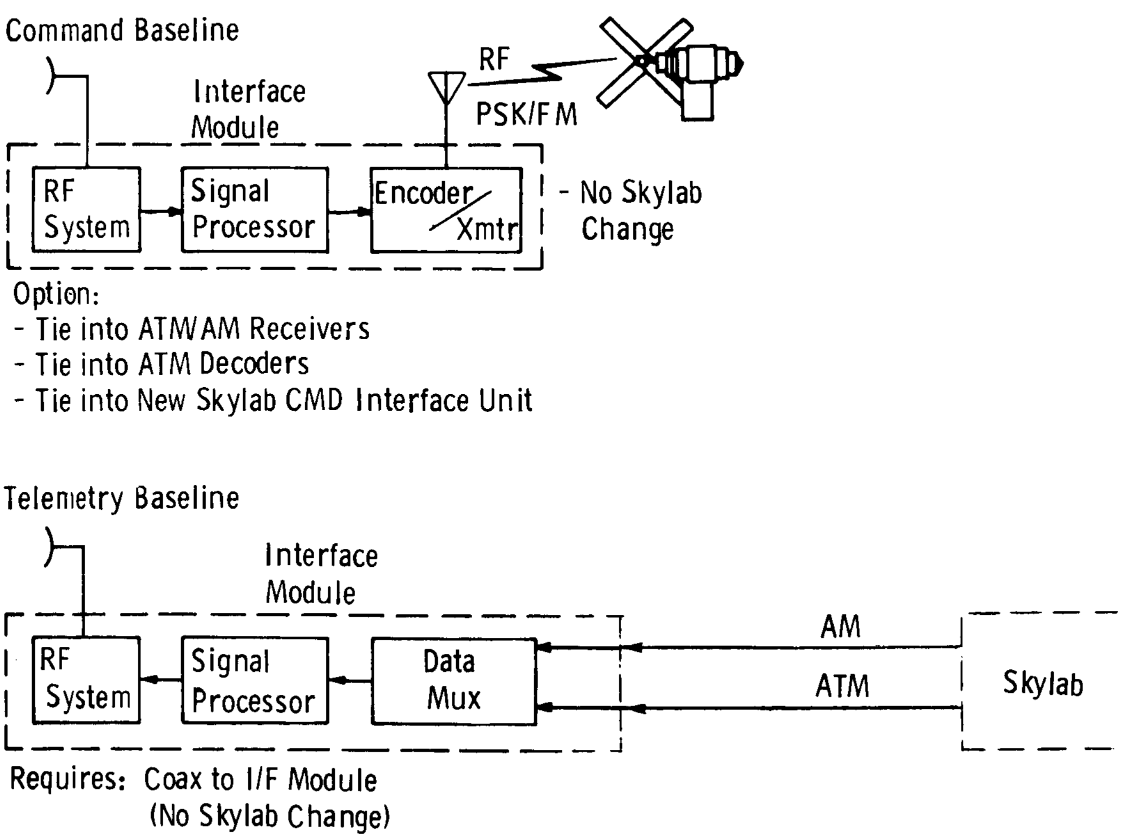


Figure 3.2-5 Command and Telemetry System Kit

The interfaces with Skylab are RF PSK/FM for command system and hardwired for the telemetry system. To accomplish the telemetry interface, an astronaut will need to perform EVA demating of an ATM signal cable and remating to a feed thru external to the Interface Module.

3.2.2 Patch and Seal Kit

Tool and repair kits were included in the Skylab on-orbit stowage in the MDA and OWS. Hard tools, such as wrenches, are completely useable on a future mission. Soft items, such as patches and adhesives, may have degraded in the space environment, and should be replaced.

The approach for finding leaks on previous Skylab missions was for the crew to listen for the sound of escaping air, locate the source of the sound, and apply a suitable repair patch or sealant. This procedure was not necessary because Skylab held its pressure remarkably well within normal allowable leakage rate projections. On future missions of the 1980s, a suitable leak detector should be available. It likely would be based on current technology using hot wire or mass spectrometer instruments (sensing air velocity or air molecules, respectively).

<u>Concept</u>

- Patches and sealants on-board Skylab may have deteriorated
- Resupply similar contents on first refurb flight
- Return on-board degradables for long exposure analyses

<u>History</u>

- Tool and repair kits stowed in MDA and in OWS (Containers M-144, E-620, E-623)
- Expendables were not needed

  -- No Measurable Leakage, 1973-1974

- Approaches to an internal leak detector were studied, but without success

Approach

- Resupply possible degradable items
- Add a portable leak detector (hot-wire or mass spectrometer)
- Use procedures available from former mission
- Add procedures for use of leak detector
- Develop means for applying external patches

Table 3.2-2 shows the patch and seal equipment. Various o-ring packing and seals, one spare MDA hatch seal, and three inboard hatch seals (for the trash airlock) are stowed in Skylab. These may require replacement and inclusion in the kit.

Table 3.2-2 Patch and Seal Equipment

Item	Size (in)	Quantity
Meteroid Penetration Repair Patch	3 X 3 X .19	10
Repair Patch, Dome	.31 X 5.75 Diam.	4
Repair Patch, Dome	1.50 X 7.25 Diam.	4
Repair Patch, Dome	1.50 X 8.37 Diam.	4
Plumbers Tape & Duct Tape		2
$PPCO_2$ Seal Kit		1
Press. Sensitive Tape	2 in. X 150 ft	1
Press. Sensitive Tape	3/4 in. X 150 ft	1
Press. Sensitive Tape, Red	1 in. X 150 ft	1
Flat Patch	3	1
Blister Patch	3/4	5
Blister Patch	1/4	7
Blister Patch	1/2	
Polybutene Sealant		
Portable Leak Detector	3 X 8 X 8	1

Total Weight
15 lbs

3.2.3 Coolant Loop Refurbishment

Coolant Loop Kit

During the original SL-3 mission, the primary coolant loop developed a leak and the kit was prepared and flown on SL-4. The loop was repaired by installing a saddle valve and flowing the coolanol under pressure. The pressure bottle contained forty-two pounds when flown and only seven pounds were used when filling the loop.

The pressure was recently checked during interrogation and no apparent leakage occurred during the years since the last manned mission. However, after the loop was turned on, a need for recharge was established.

The original tank and kit should provide ample coolant to recharge both loops, as approximately 16 to 20 pounds should be required.

Concept

- Use onboard kit, consists of:
  - Reservoir tank/leak check/fill manifold
  - Leak check/fill hoses
  - (3) saddle valves (one in place on primary loop)
  - Ancillary installation tools (screwdrivers, pliers, ratchets, etc.)
- Return kit for recharge, reflight

Servicing the coolant loop with the onboard kit requires approximately three-hours with the majority of the time spent in set up and check out. The procedure was performed on the last manned Skylab mission for the primary loop. At that time the crew spent much time getting to the coolant line. This time can be reduced by use of a special tool which is part of the kit. The earlier crew was unaware the tool was onboard and did not mention any problem to the ground operations support team.

The photograph in Figure 3.2-6 shows the reservoir and manifold used for leak checking and filling the coolant loop. The photograph was taken during training prior to SL-4.

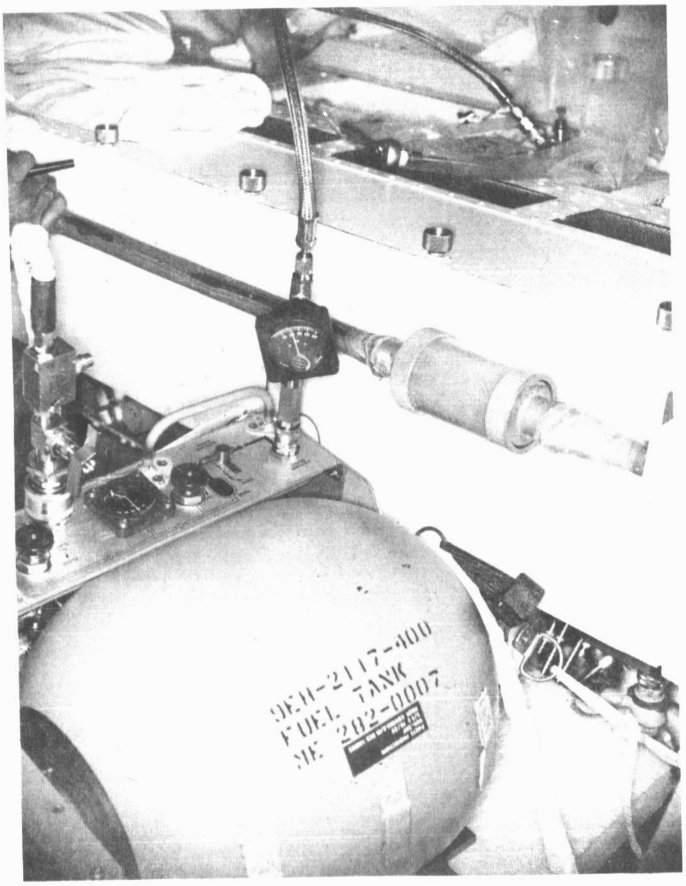


Figure 3.2-6 Coolant Loop Servicing

3.2.4 Communications Refurbishment Kits

The Skylab Reuse Program requires upgrading the communications subsystem after Phase I operations to provide television required experiment data rates as mission complexity progresses. The communications refurbishment kit upgrades the communications subsystem in an evolutionary manner spreading program costs, but providing required capability at the needed time. Figures 3.2-7 and 3.2-8 depict this basic approach for untended and tended operations.

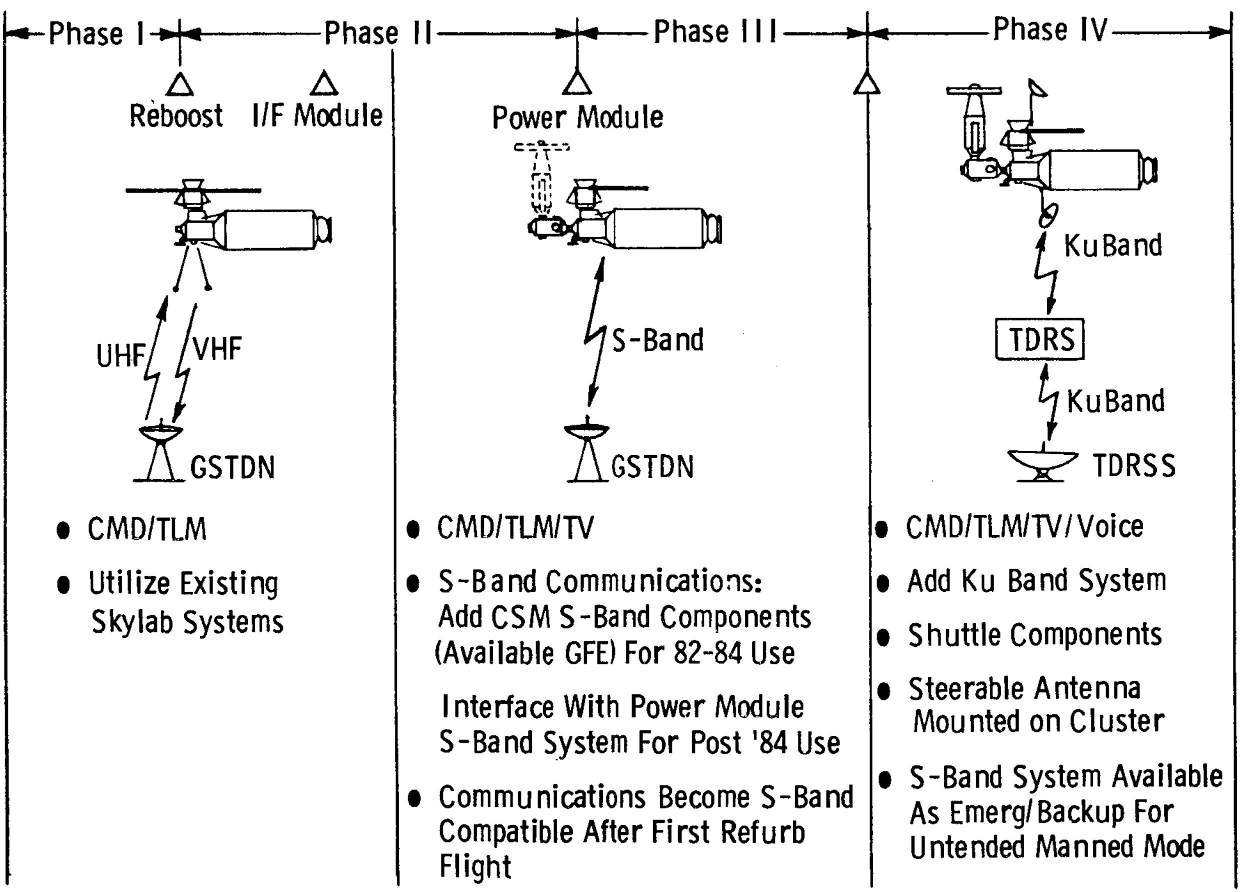


Figure 3.2-7 Communications Evolutionary Approach - Untended Mode

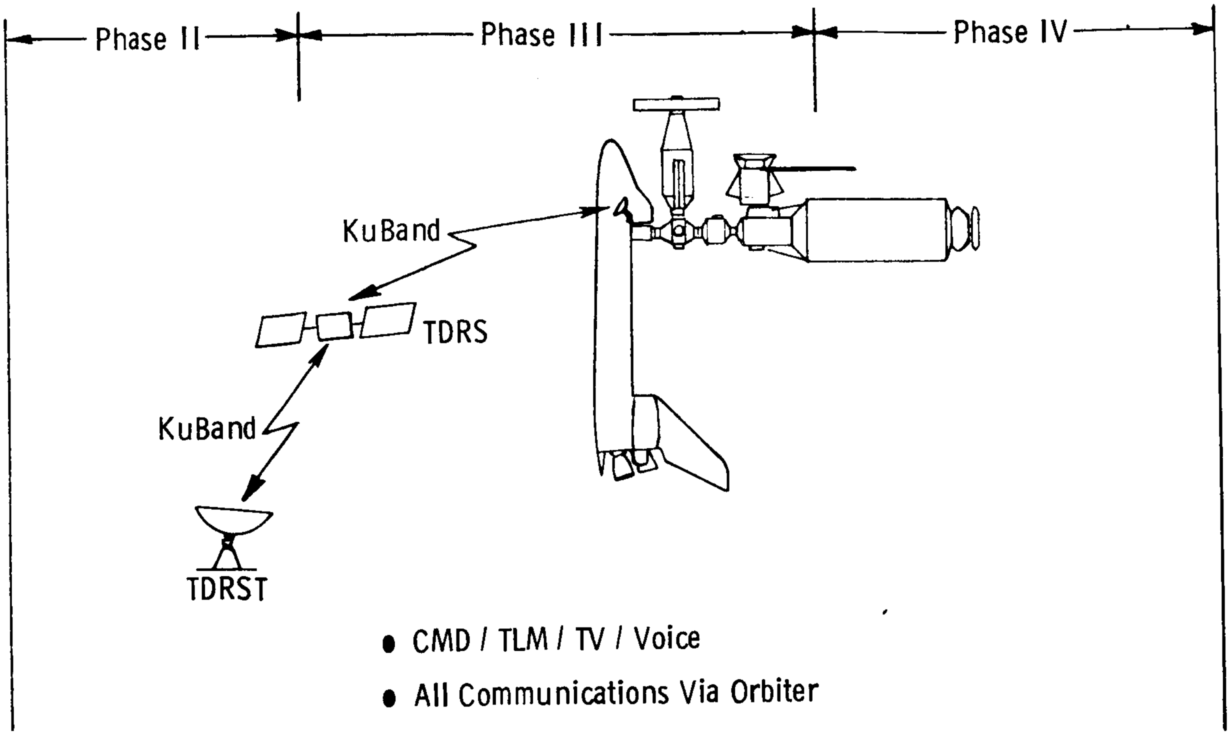
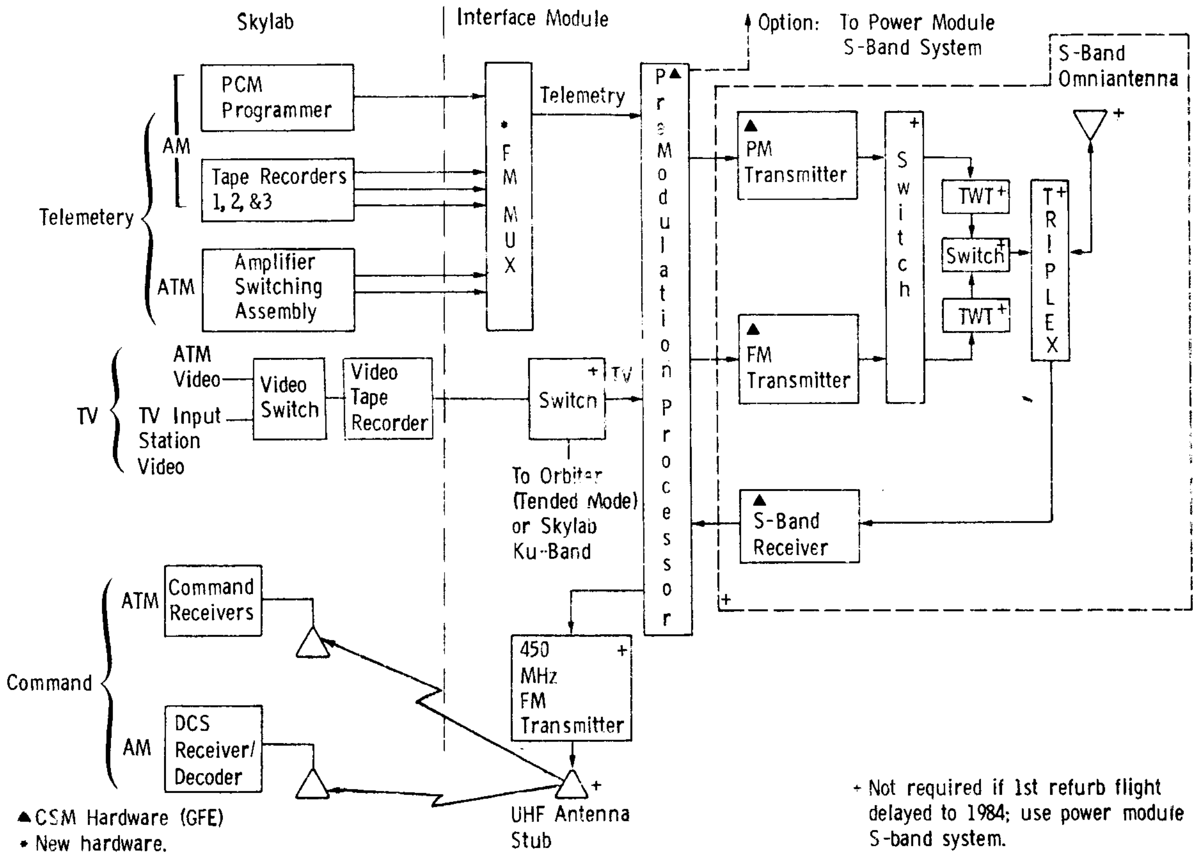


Figure 3.2-8 Communications Evolutionary Approach - Tended Mode

Initial operations on Skylab will utilize the onboard UHF command link for control and VHF telemetry link for monitoring functions. Beginning with Phase II, this system will be superseded by an S-Band system installed in the Interface Module which will carry command, telemetry, and television. This S-Band system is composed of available CSM hardware duplicating the CSM S-Band system. Additionally, an FM multiplexer is required to interleave ATM and AM data prior to being input to the RF system. This S-band system can also serve as a backup/emergency system to the Ku Band system during manned untended missions in Phase IV. A block diagram of the proposed S-band system is shown in Figure 3.2-9. Although not shown in the figures, this system contains the hardware for voice transmission.

As an option, the first refurbishment flight may be delayed until the Power Module is available (1984). In this case, the RF components could be eliminated from the Interface Module and Skylab communications requirements could be satisfied by the Power Module S-Band system. This approach requires that the multiplexing of the AM and ATM data include some data compression to make the bit rate compatible with Power Module's 64 KBPS transmission capability.

For Phase IV operations, increased experiment data requirements dictate the use of a Ku-Band system. For use in both untended, as well as tended modes, this system,made up of equivalent Orbiter Ku-Band hardware, will be built into the Interface Module.



Voice capability included (not shown in figure)

Figure 3.2-9 S-Band Communication System

When the Shuttle Orbiter is docked to the Skylab/Interface Module/Power Module Cluster, the communication link is via the Orbiter Ku-band system, through TDRS, and to TDRSS ground station. During the refurbishment flights, interfaces will be developed to integrate Skylab TV, voice, command, and telemetry with the Orbiter Ku band. Other components include a Spacelab high-rate multiplexer and a Spacelab high-rate recorder to handle the increased data rate. Figure 3.2-10 is a block diagram of the Ku-band system required for Orbiter tended operations.

For the untended mode additional equivalent Orbiter hardware and interfaces will be required, as shown in Figure 3.2-11. A steerable RF antenna, requiring EVA for mounting, is needed. Transmission in untended operations will be via this Skylab Ku-band antenna to the Orbiter Ku-band System.

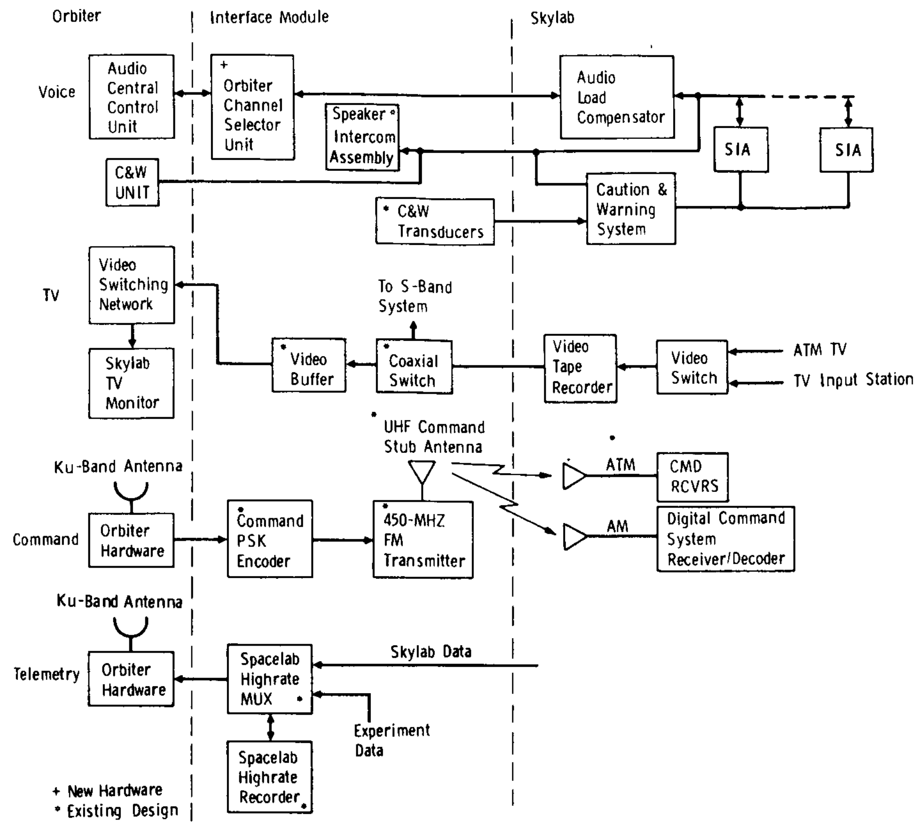


Figure 3.2-10 Kμ-Band System - Tended Mode

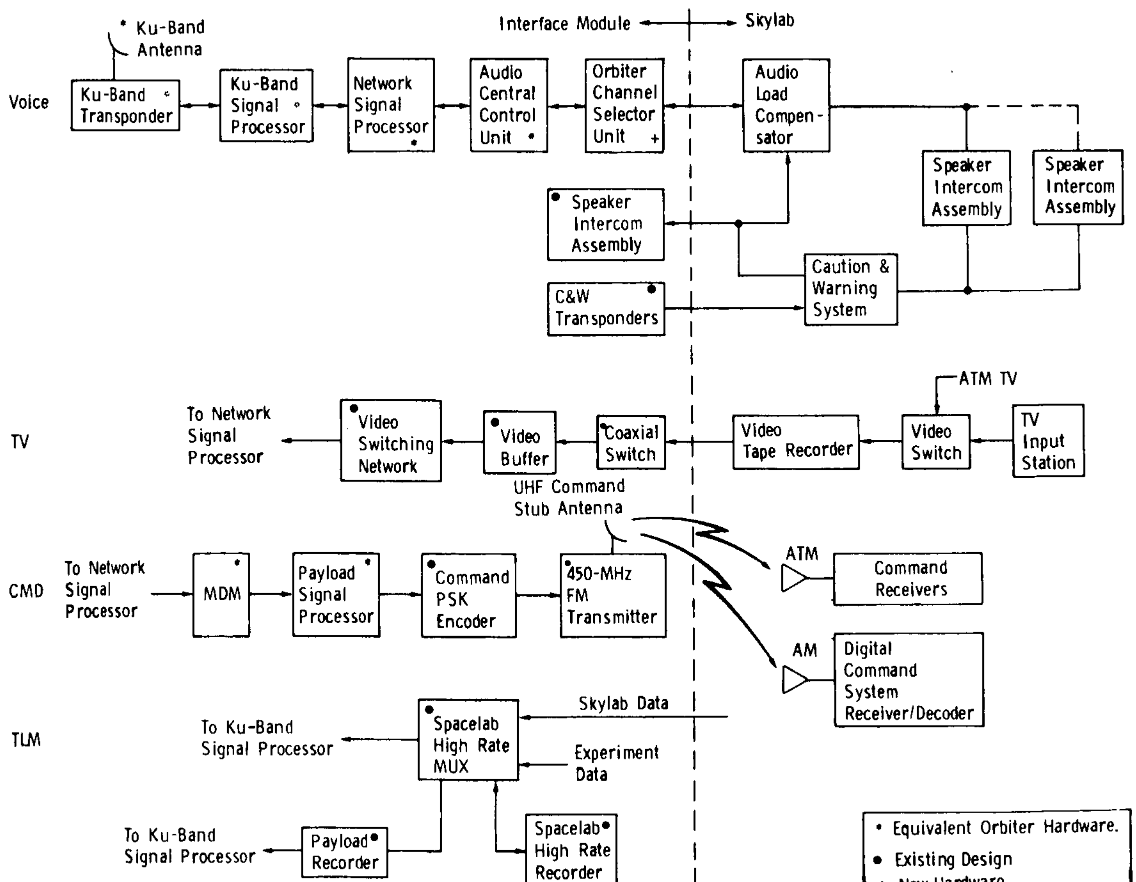
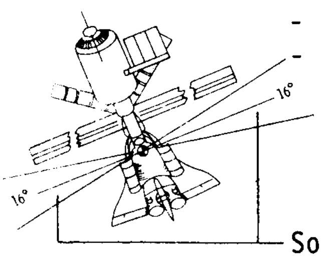


Figure 3.2-11 Kμ-Band System - Untended Mode

3.2.5 Sun Shield

During refurbishment missions, the Cluster can be held in an orientation near the original solar inertial, with the existing parasol sun shield providing thermal shielding of the gold kapton area of OWS. The parasol is adequate for Skylab operations in Phase III until instruments with pointing requirements cause orientations in other attitudes. At this point, a sun shield covering the gold kapton area will be required, since the sun can come from nearly any radial direction. The sun shield concept is shown in Figure 3.2-12.

Rationale



Solar Exclusion Cone

Internal Temperatures

- 1973: 54.4°C (130°F)
- Stored: to 135°C (275°F)
- 1978 Test: 38 to 49°C (100 to 120°F)

- Existing parasol adequate for near solar inertial attitude during refurb flights.
- Sun comes from most directions for pointed experiments.
- May interrogation test shows low leakage rates: Probably no holes.
- Baseline soft cover; install during Phase III.

Requirements

1. Cover Gold-Plated Kapton Area
2. Leave Window & Airlocks Clear
3. Provide 10-Year Durability
4. Compatible with Shuttle Launch
5. Installation with Simple EVA Tools
6. Provide Thermal Control in All Attitudes (May Require Special Design)

Equipment List

	Quantity	Weight, kg	Size, m	
Soft Cover				
Cover, Pack, Cord, Fittings	1	140	0.6x0.8x0.8	New
Crew Mobility Aids	1	133	in FSS	MMU-GFE
Orbiter Launch Restraints	1	20		New-Holds Cover

Figure 3.2-12 Skylab Reuse Sun Shield

The sun shield can be either hard (aluminum) or soft (similar to the existing parasol). Recent interrogation tests (vehicle pressurized) indicate no meteroid punctures to date. We have therefore baselined a soft cover. This cover is contained in a parachute pack, deployed by EVA crewmen, and secured to Skylab using straps and hooks. No scarring of the OWS is required.

The soft cover sun shield is a light-coated fabric packed in a parachute type pack that is transported in the Shuttle Orbiter (Figure 3.2-13). The pack is translated to the AM TRUSS area by a crewman using the MMU as shown in Figure 3.2-14. The

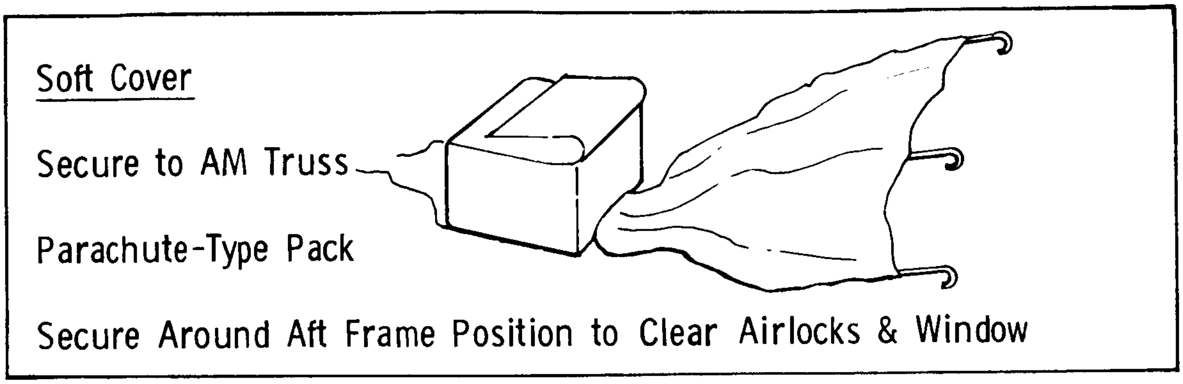


Figure 3.2-13 Sun Shield Soft Cover

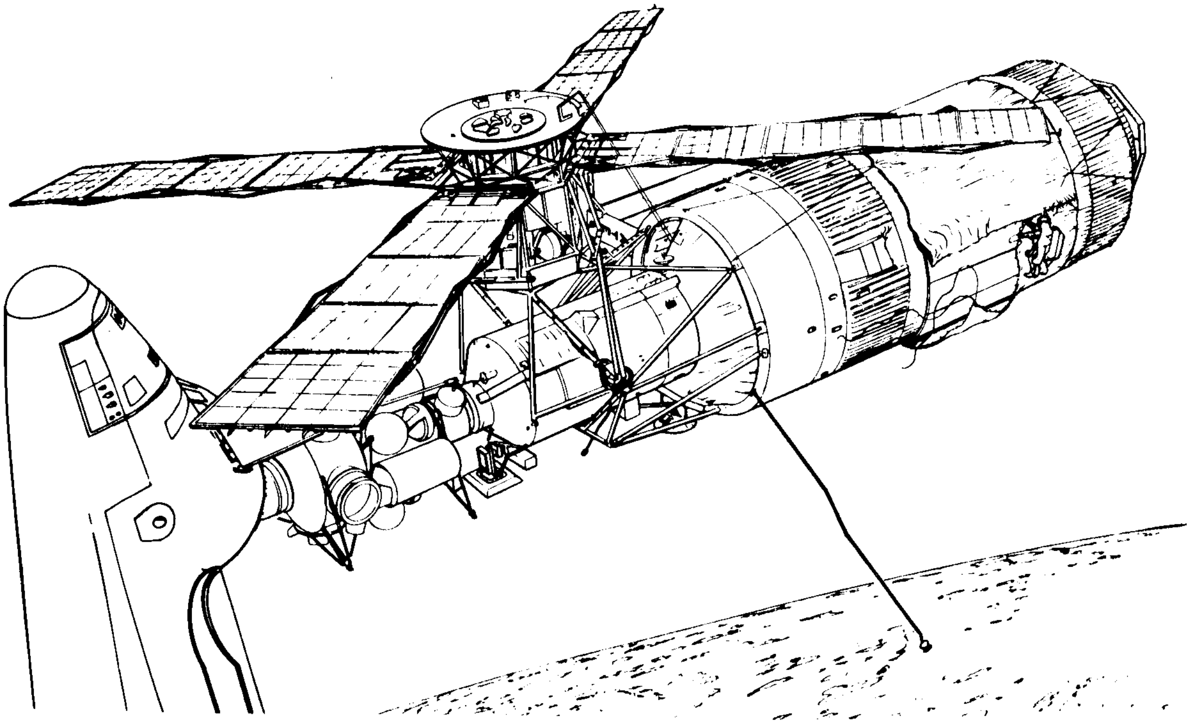


Figure 3.2-14 Sun Shield Installation

second crewman helps attach the chute pack to the AM truss Present sun shields are then removed and stowed. The sun shield is deployed and attached by the forward and aft restraints into the external skirt hat stringers. The crewman with an MMU aids in the wrap around maneuver until the total shield is in place and secured. Installation should be possible in one EVA period (Figure 3.2-15).

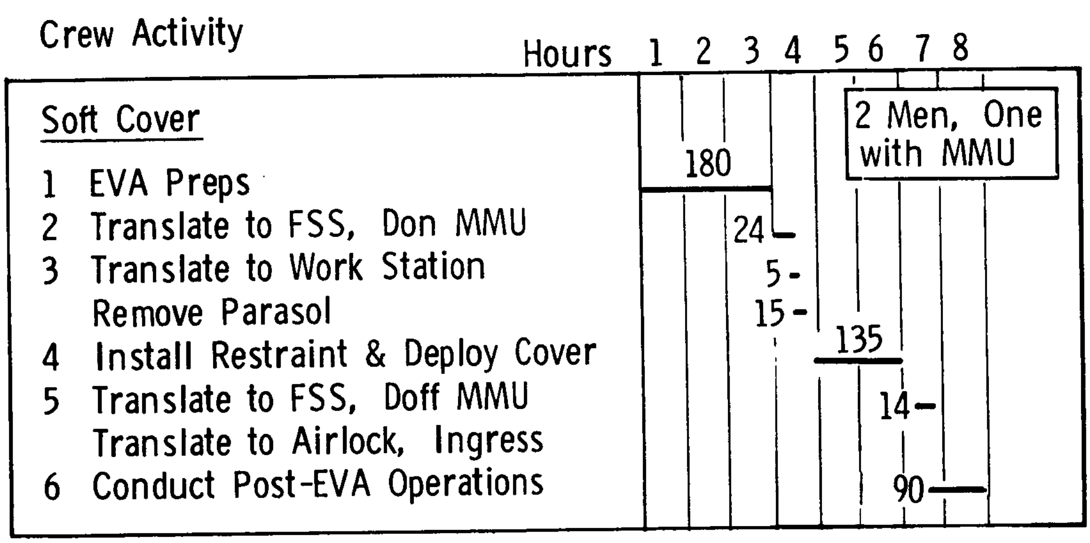


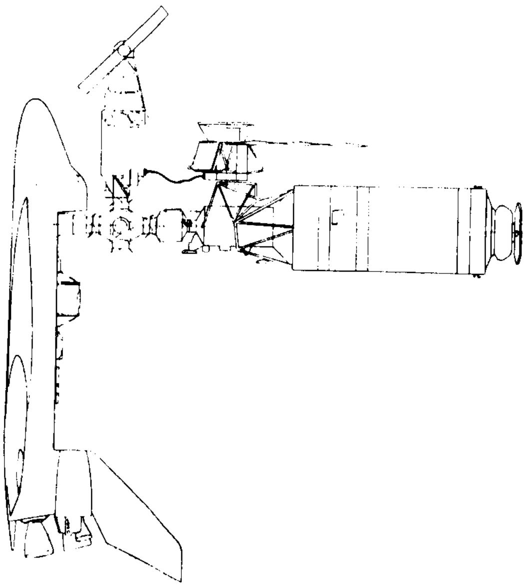
Figure 3.2-15 Sun Shield Installation Timeline

3.2.6 Power Transfer Kit

The Power Transfer Kit transfers electrical power from the Power Module to Skylab supplementing Skylab's power operation capability. Up to 8 kW transfer could be required for a 7-man crew in Skylab, assuming total loss of Skylab power generation or orientations with the backs of the existing Skylab arrays toward the sun.

Power transfer cables will interface with the ATM power system through the MDA/CSM interface connectors located in the MDA axial docking port. Installation of the ATM interface cable requires EVA operations, while the MDA interface connector is installed internally.

Figure 3.2-16 shows the general physical arrangement and the proposed routing of the power transfer cables, as well as requirements and an estimated crew activity timeline for installation and checkout of the cables.



Concept

Two cable assemblies to interface with Skylab at 2 points:

- ATM (external) at GSE ground test connectors routed from external Power Module connector
- MDA (internal) at MDA/CSM interface connector, routed internally from Power Module through interface module

Installation & Checkout

Event	Time Min
• Translate to I/F Module, obtain cables	10
• Connect cable to Power Module, verify proper voltage on connector pins	20
• Connect cable to MDA conn.	5
• Translate to ATM	15
• Connect cable to external Power Module connector • Verify proper voltage on connector pins	25
• Connect cable to ATM connectors	10

Requirements

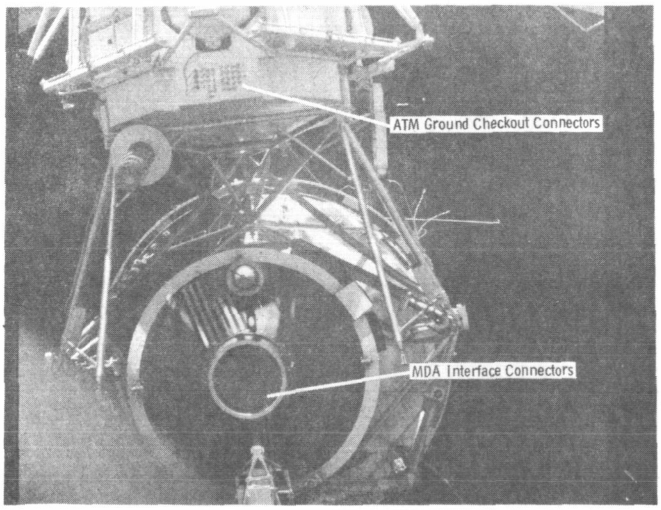
- Transfer up to 5.5 KW to ATM Interface
- Transfer up to 2.5 KW to MDA Interface

Figure 3.2-16 Power Transfer Requirements, Concept, Installation and Checkout

Figure 3.2-17 shows the general areas of the ATM and MDA where the power transfer interfaces are located and describes the equipment and training requirements required.

The astronaut activities involved with installation of the power transfer cables will require neutral bouyancy simulation to develop and verify crew procedures, classroom training, and 1-g "hands on" training to familarize the astronauts with interfaces and procedures. A set of neutral buoyancy hardware is required to support this activity.

This kit will be carried on the second refurbishment flight and installed after the Power Module is docked to the Cluster.



Equipment	Size	Wt
Flt PM/MDA Cable Set	10 ft	10 lbs
Flt PM/ATM Cable Set	15 ft	15 lbs
Neutral Buoyancy PM/MDA Cable Set	10 ft	10 lbs
Neutral Buoyancy PM/ATM Cable Set	15 ft	15 lbs
Connector Pliers		
Checkout Kit		3 lbs

Training Requirements

- Neutral Bouyancy Simulation Develop & Verify Procedures
- 1-G "Hands-On" Training
- Classroom Training

Figure 3.2-17 Power Transfer Equipment and Training

3.2.7 Skylab Water Resupply

The present Skylab water supply is approximately 2590 pounds (39% of full complement). The purity of the water is not known. The planned replacement concept is to refill the tanks on either the second visit or on a later resupply flight (Figure 3.2-18). During the first refurbishment flight, equipment required to perform the refill task will be installed, the system checked, and water samples obtained from each tank and returned to ground for analysis.

During the resupply flight, water will be carried either in the Logistic Module or on a Spacelab pallet. On-board water will be purged or treated, as determined from the analysis performed on ground.

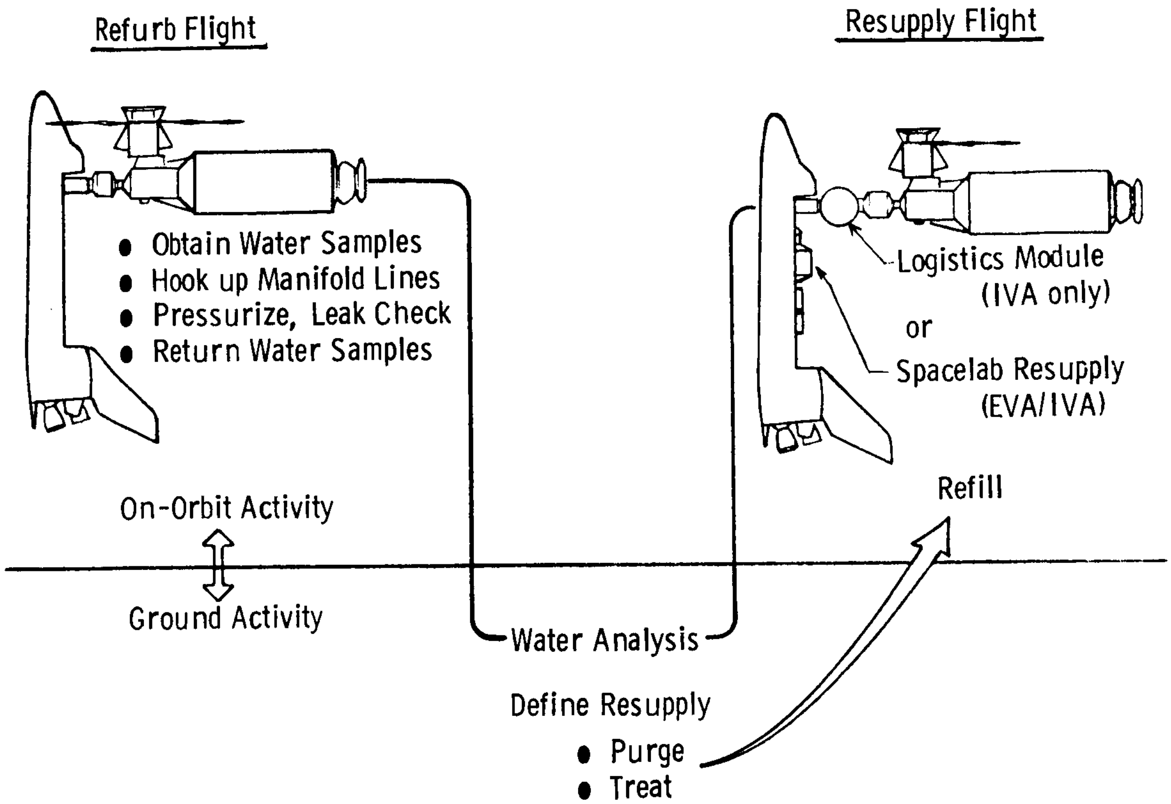
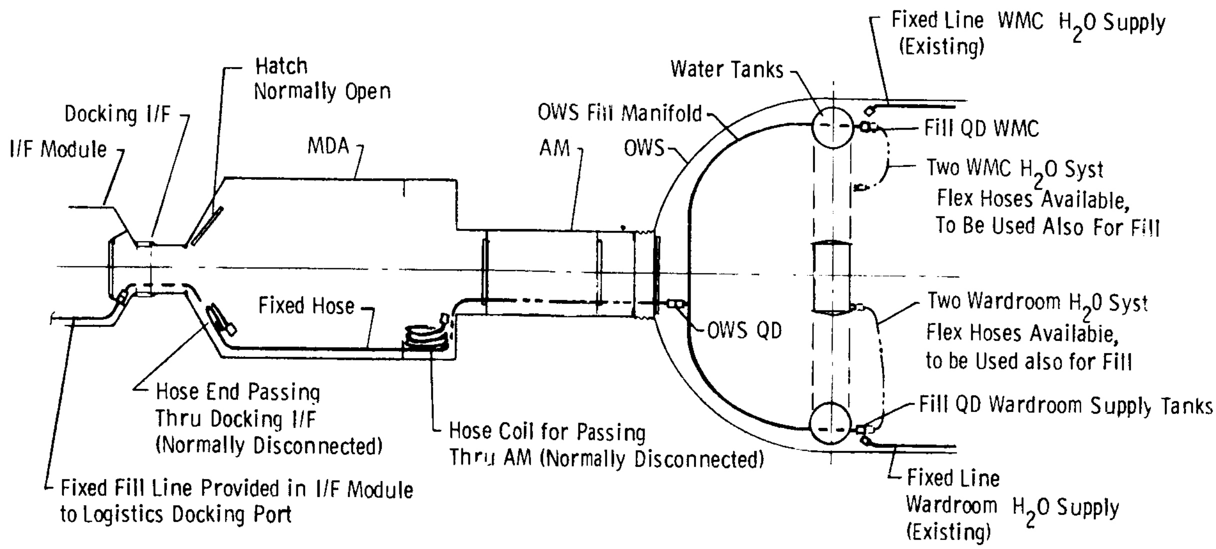


Figure 3.2-18 Water Resupply Concept

The water resupply equipment is shown in Figure 3.2-19 A flex water hose, 1/2" I.D. and approximately 45 ft. long will be mounted in the MDA. Each end will be coiled and stowed free of airlocks. When in use, this hose will be routed through the docking interface and attached to the Interface Module (IM) bulkhead fitting. The other end will be routed through the AM and OWS forward hatches and connected to the OWS fill manifold Quick Disconnect (QD).

The OWS fill manifold, about 40 ft. long, will be permanently installed in the forward dome of the OWS. A QD T-fitting allows one hose to run to the vicinity of the wardroom H_2O supply hardline QD (below tank 2); the other going opposite to the vicinity of the Waste Management Compartment (WMC) H_2O supply hardline QD (between tanks 6 and 7). The lines will be secured to the OWS forward dome walls at suitable locations. QDs are provided at the end of the fill line at both locations. Skylab flex hoses are available to hook from the fill QDs to the individual tanks. The resupply Module, the Docking Module, and the IM have permanent hardlines installed with manual



Equipment List

Description	Size
Flex Water Hose with 2 QD's	1/2" I.D. 45 Ft Long
OWS Fill Manifold, Flex Hose with 3 QD's & T-Fitting	1/2" I.D. 40 Ft Long

Figure 3.2-19 Water Resupply Equipment

QDs at all docking ports. Figure 3.2-20 shows the time required to install water resupply equipment during the refurbishment flight.

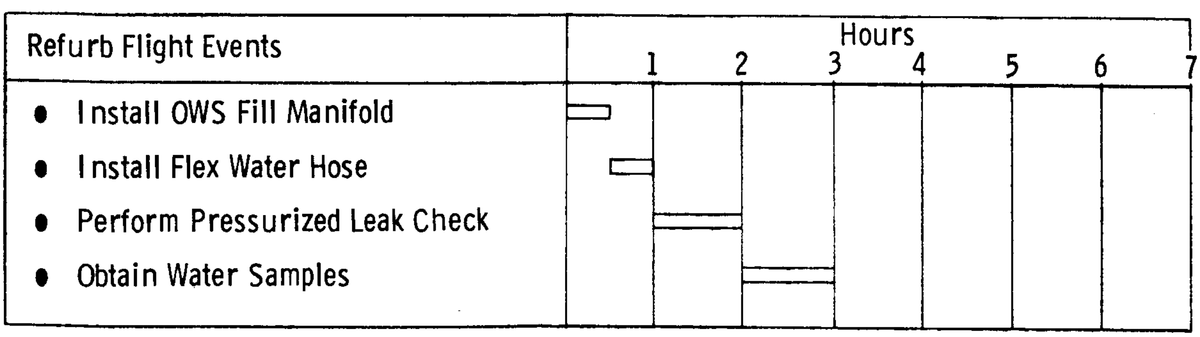
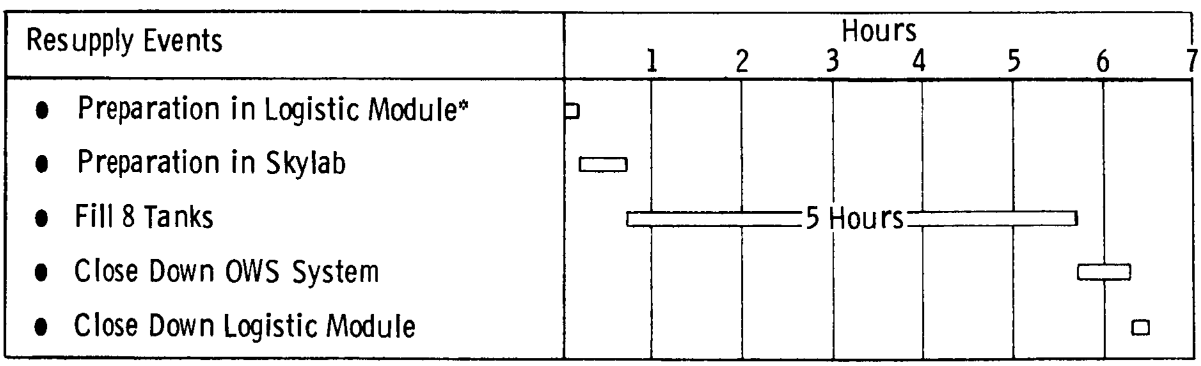


Figure 3.2-20 Refurbishment Kit Installation Timeline

The time required for a normal resupply of water on resupply missions is shown in Figure 3.2-21. Preparations in the Logistics Module include manual connections of the water fill lines on the docking port, preparations to pump water from the Logistics Module water tanks and opening the transfer valve.

To prepare for water resupply in Skylab the fill hose in the MDA is unpacked and connected to the IM bulkhead and the OWS fill manifold. The water tank pressurization system is closed and the tank bled. Then with Skylab supplied flex hoses, selected tanks are connected to the OWS fill manifold, and the tank outlet valve opened, which begins the fill process. One wardroom and one WMC tank can be filled at the same time. After all tanks are filled, Skylab tanks will be repressurized, MDA fill hose disconnected and stowed, logistics fill valve closed, and tanks depressurized.



* Add 2 Hours for EVA IF Spacelab Module Used

Figure 3.2-21 Water Resupply Timeline

Preparations in the Logistics Module include manual connections of the water fill lines on the docking port, pressurization of logistics module water tanks and opening the transfer valve.

To prepare for water resupply in Skylab the fill hose in the MDA is unpacked and connected to the IM bulkhead and the OWS fill manifold. The watertank pressurization system is closed and the tank bled. Then with Skylab supplied flex hoses, selected tanks are connected to the OWS fill manifold, and the tank outlet valve opened, which begins the fill process. One wardroom and one WMC tank can be filled at the same time. After all tanks are filled, Skylab tanks will be repressurized, MDA fill hose disconnected and stowed, logistics fill valve closed and Logistic Module tanks depressurized.

Option For Intertank Water Transfer

Because not all tank water will be used before the resupply arrives, and it is desirable to conserve water but also have the freshest water for wardroom supply, a system can be devised to transfer left-over water from the wardroom system into the WMC system by adding a three-way type individual bleed valve to the pressurization ports of tanks 6, 7, 8 and 9. By bleeding these WMC tanks individually without bleeding the pressure in the whole system, a simple water transfer is possible.

3.2.8 Shuttle Food Galley (Optional Refurbishment Kit)

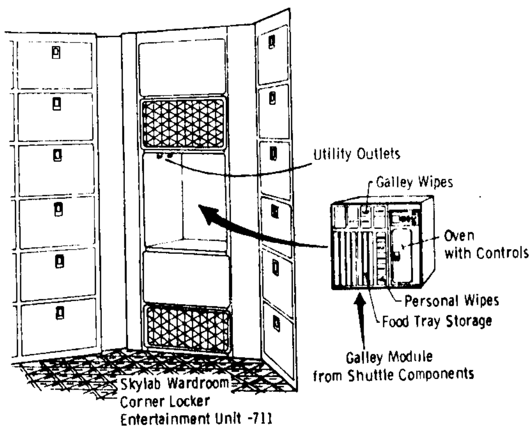
A compact galley module can be designed using Shuttle galley components, providing an oven with associated controls and stowage space for 7 Shuttle food trays. Additional drawers for galley and personal wipes can be incorporated to make a compact unit. The entertainment locker -711 space would be used to house the new galley module. Utility outlets are available at this location. The Skylab food table unit with water dispensers and hand washer in the WMC will be used. The galley addition provides commonality of food with that of the Space Shuttle. It is presented here as a low-cost optional supplement to Skylab wardroom food preparation facilities.

Optional Installation; Provides the Following:

- Standardizes food type with Orbiter
- Expands galley facilities

Concept

- Carry on kit containing shuttle oven trays, wipes
- Retain use of Skylab land washer and water dispenser

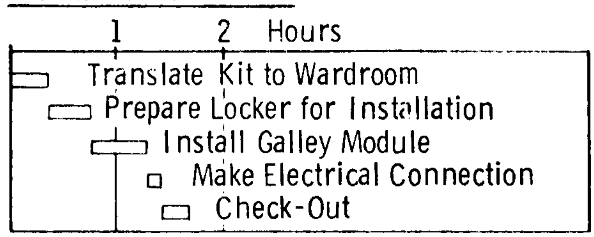


Requirement

- Power connection: 500W
- 25 W x 23 H x 16 D envelope

Equipment	Weight
Oven	21 lb
Food trays (7)	6 lb
Frame	9 lb
Secondary Structure	6 lb

Installation Time Line



- Installation: Phase III (1984 or later)
- Training: l-g only, use protoflight unit

Figure 3.2-22 Shuttle Food Galley Installation in Skylab

3.2.9 Waste Management System

The waste management system was operational at the end of the last Skylab mission. Since the internal OWS temperatures have not been extreme since, it is assumed that the system is operational.

The assumptions and concepts for updating the system are:

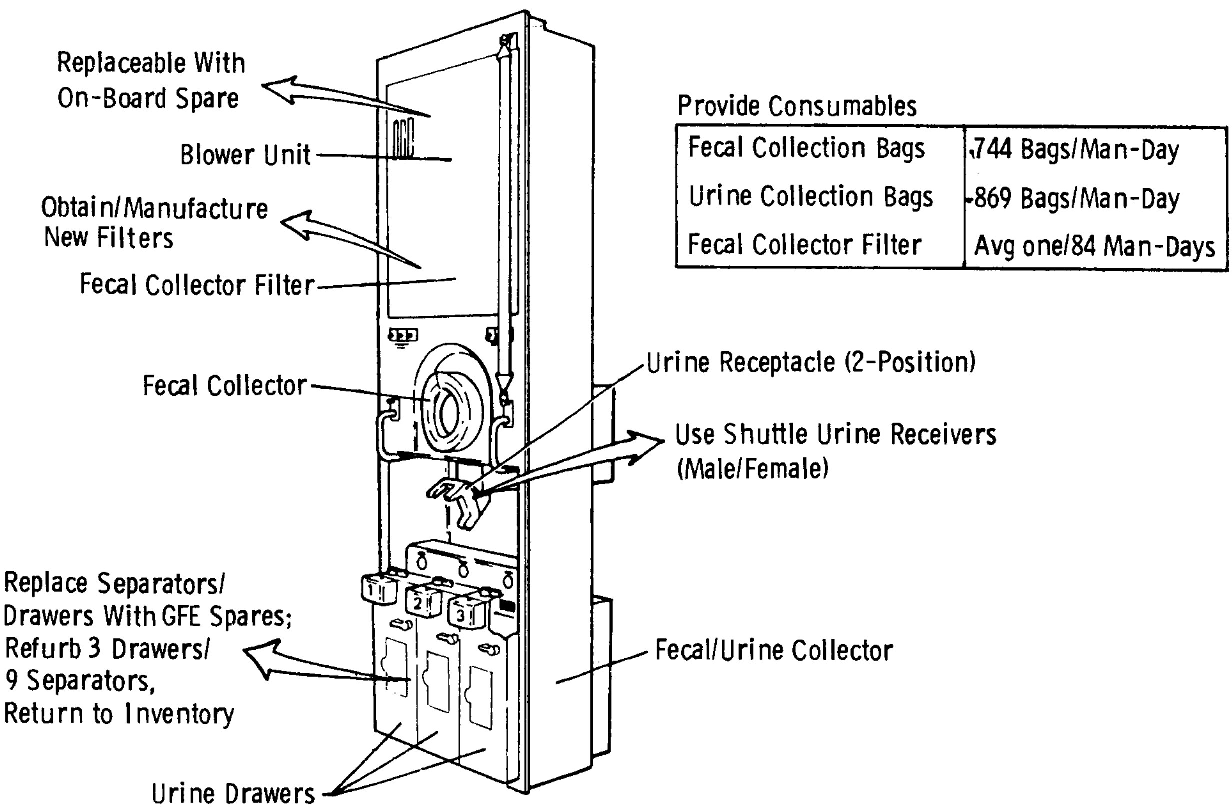
Assumptions

- Biomedical sampling/return required only periodically
- System remains operational
- Shuttle urine cuffs (male and female) and inlet lines available for Skylab use

Concept

- Use Orbiter WMS during refurbishment missions
- Checkout Skylab system using SL-2 urine separators
- Remove urine drawers (3) for return: hand tools required
- Return used urine separators (9) for cleaning/use as spares
- Install GFE drawers and separators
- Retrofit shuttle urine inlet lines with Skylab urine separator connection fitting
- Obtain/manufacture and resupply collection bags and wipes

Figure 3.2-23 shows the concept of updating and refurbishing the Skylab Waste Management System. Urine drawers and separators from the system will be removed and replaced with GFE drawers and separators. Skylab urine cuff will be refilled with shuttle cuffs to allow both male and female use. Shuttle urine inlet lines will be retrofitted with Skylab urine separator connection fitting.



Fecal Collection Bags	.744 Bags/Man-Day
Urine Collection Bags	.869 Bags/Man-Day
Fecal Collector Filter	Avg one/84 Man-Days

Figure 3.2-23 Waste Management System Refurbishment

3.2.10 Oxygen and Nitrogen Recharge

Recent interrogations from the ground have shown that the oxygen and nitrogen system (which supplies breathing air to the Cluster) is sound. Only resupply is required to operate the system in the original Skylab missions. This section defines an approach to resupplying the oxygen and nitrogen tanks on orbit.

Figure 3.2-24 shows the proposed resupply concept. Resupply lines are manifolded to the tanks and routed to an external connection panel on the Interface Module. Resupply is provided by connecting the supply system of a Logistics Module on the Interface Module to the permanently attached O_2 and N_2 lines. Gases are pumped into the tanks from the Logistics Module.

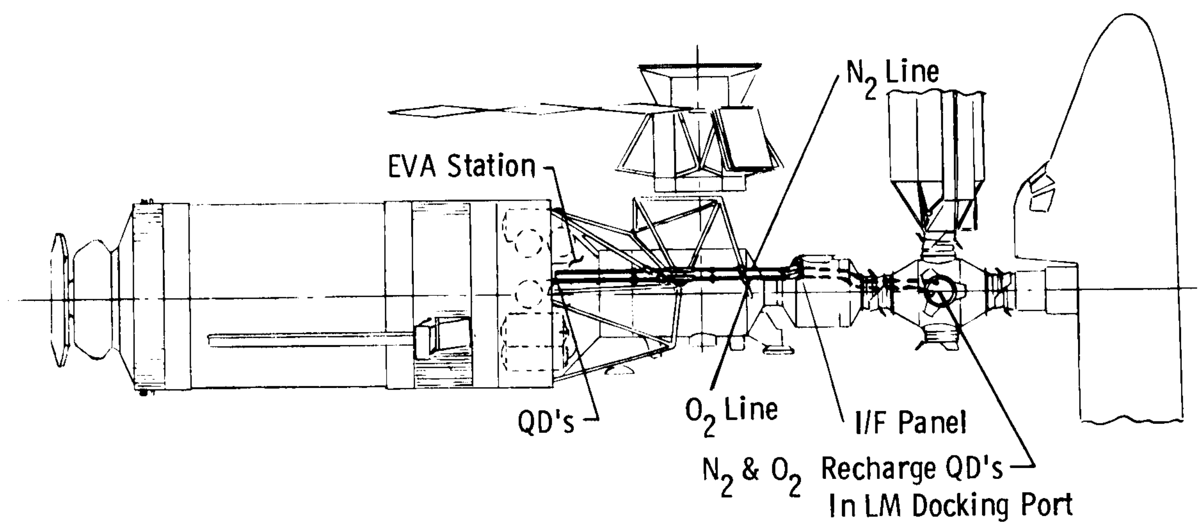


Figure 3.2-24 Resupply of Atmospheric Oxygen and Nitrogen

Oxygen and nitrogen tanks are shown in the two parts of Figure 3.2-25. The photographs were taken during Skylab assembly. The fill ports for the oxygen tanks are on the aft end of each tank, with the connector panel located at the outboard edge. Access to oxygen tanks (and to three of the nitrogen tanks) is through the thermal curtain. This curtain can be unfastened to provide access to the tank area. Figure 3.2-25 also shows the nitrogen tanks mounted on the Airlock Module Trusses. Fill ports are accessible by opening the thermal blankets.

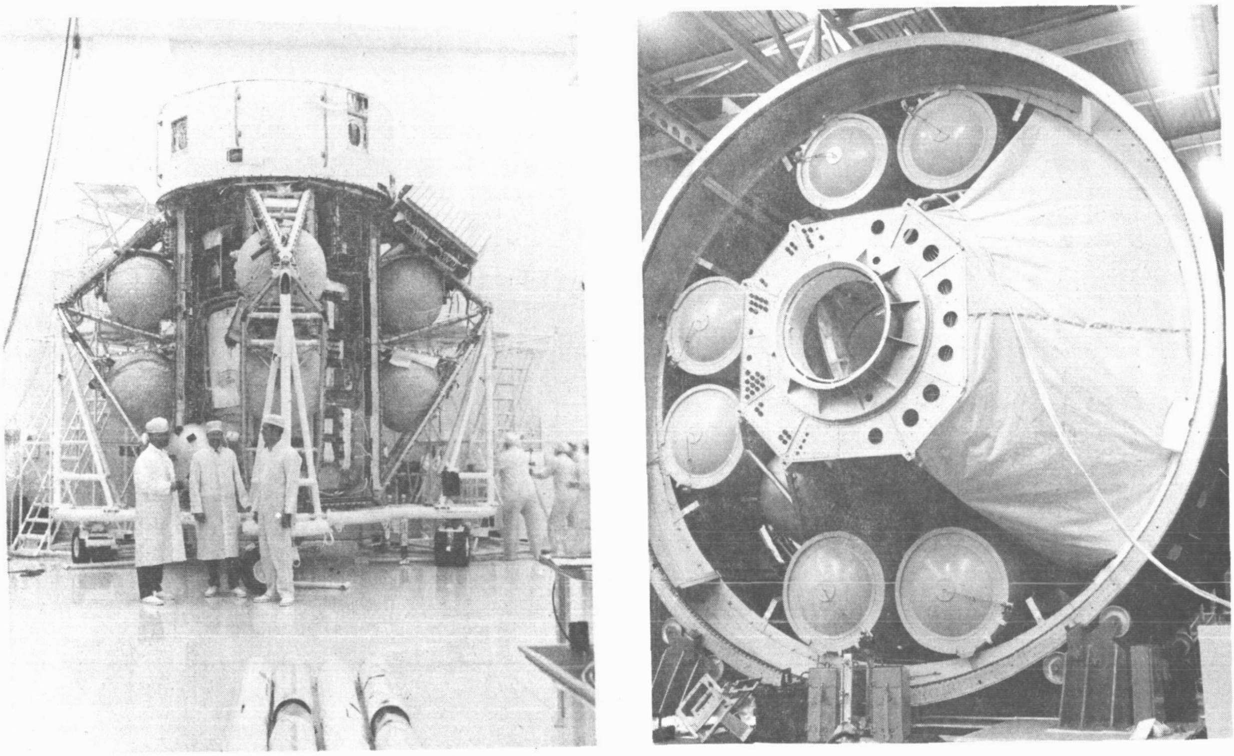
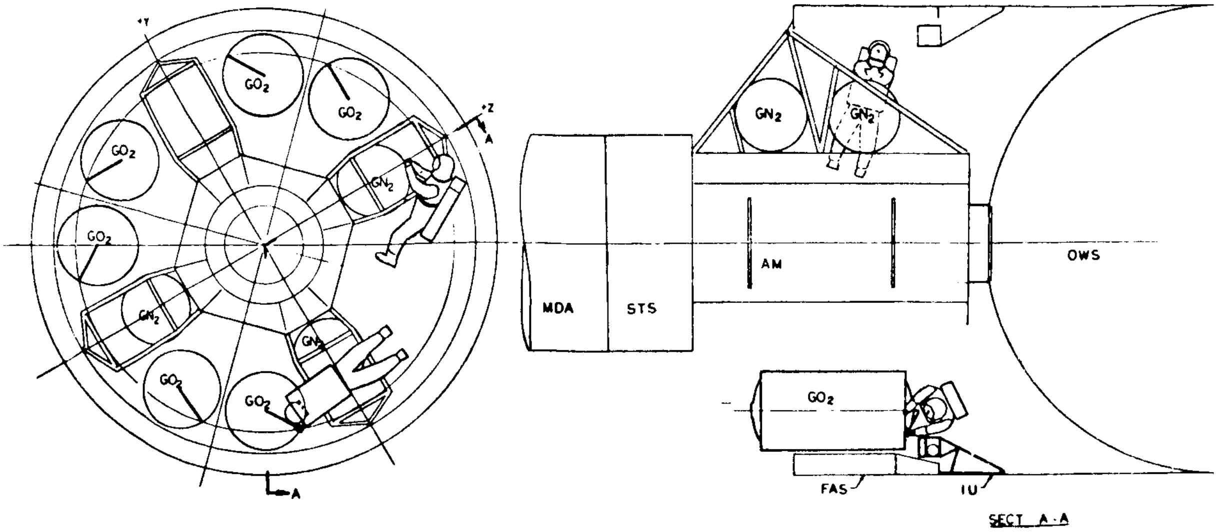


Figure 3.2-25 Oxygen and Nitrogen Tanks in Skylab

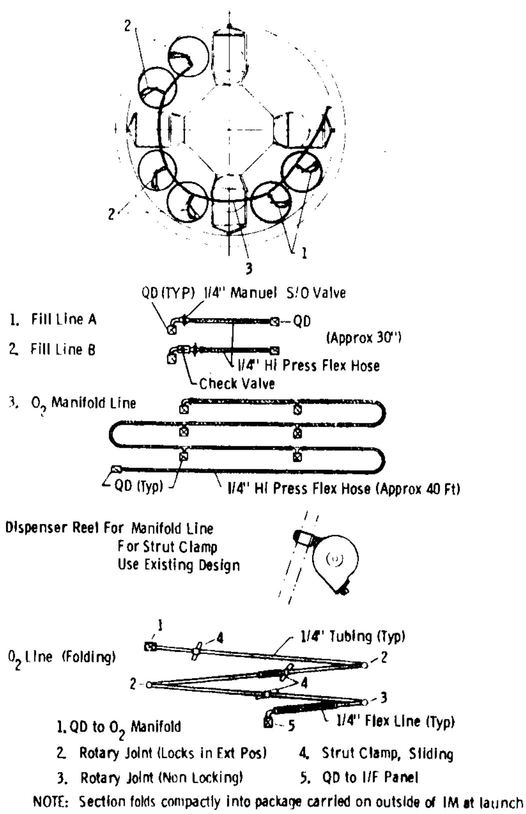
Layouts were made to see if a suited astronaut could reach the fill points on the oxygen and nitrogen tanks (Figure 3.2-26). Access to the oxygen tank fill ports is partially restricted by the Instrument Unit truss that supports an air conditioning duct. But, based on the layouts made and checks of the one-g trainer at JSC, we feel most of the fill points can be reached. We have, therefore, baselined the manifolding of the tanks without addition of tanks on the Interface Module. (Note that the Interface Module designs are compatible with adding tanks either for this purpose or for TACS resupply).

Hardware required for the oxygen manifold and fill refurbishment kit is illustrated in Figure 3.2-27. Fill lines, manifold line, dispenser reel (for the manifold line), required rotary joints, quick disconnects, and clamps are shown along with sizes and estimated weights. Although either approach could have been taken, rotary joints were chosen over flex lines because of lighter weight and denser packaging.



Layout, Observation of I-G Trainer, Smithsonian Hardware Shows Manifold Feasibility

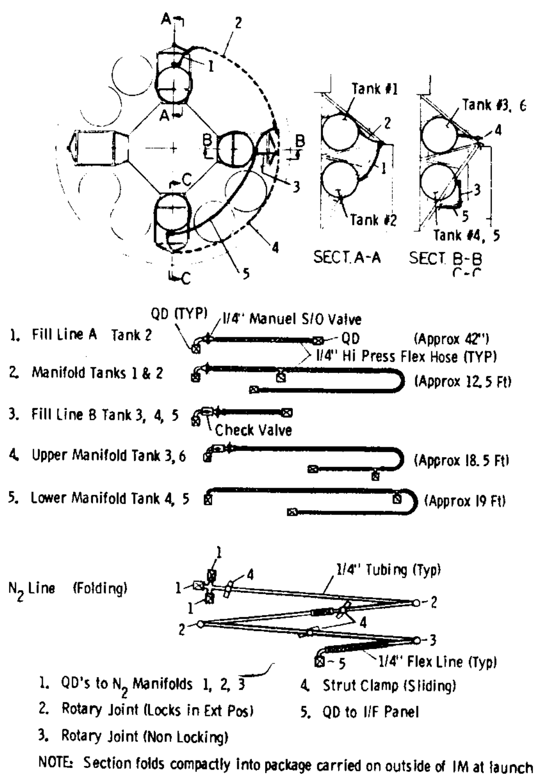
Figure 3.2-26 Crew Access to Oxygen and Nitrogen Systems



Equipment	Weight (Kg)	Size (M)
Oxygen Manifold	9.9	12.2
Dispenser Reel		
Fill Line A	.9	0.8
Fill Line B	1.0	0.8
Fill Line Ass'y	4.5	7.9

Figure 3.2-27 Oxygen System Hardware

The nitrogen hardware is illustrated (Figure 3.2-28) with components and weights listed. Hardware is stowed on the Interface Module prior to the EVA installation activity.



Equipment	Weight (Kg)	Size (M)
Nitrogen Upper Manifold (Tanks 3 & 6)	4.9	5.6
Nitrogen Lower Manifold (Tanks 4 & 5)	4.7	5.8
Nitrogen Manifold (Tanks 1 & 2)	3.3	3.8
Fill Line A (Tank 2)	1.1	1.1
Fill Lines B (Tanks 3, 4 & 5)	1.0	0.8
Fill Line Ass'y	4.5	7.9

Figure 3.2-28 Nitrogen System Hardware

Figure 3.2-29 illustrates the EVA timeline for installing the O_2 and N_2 manifold lines and fill lines. Total EVA estimate is six hours.

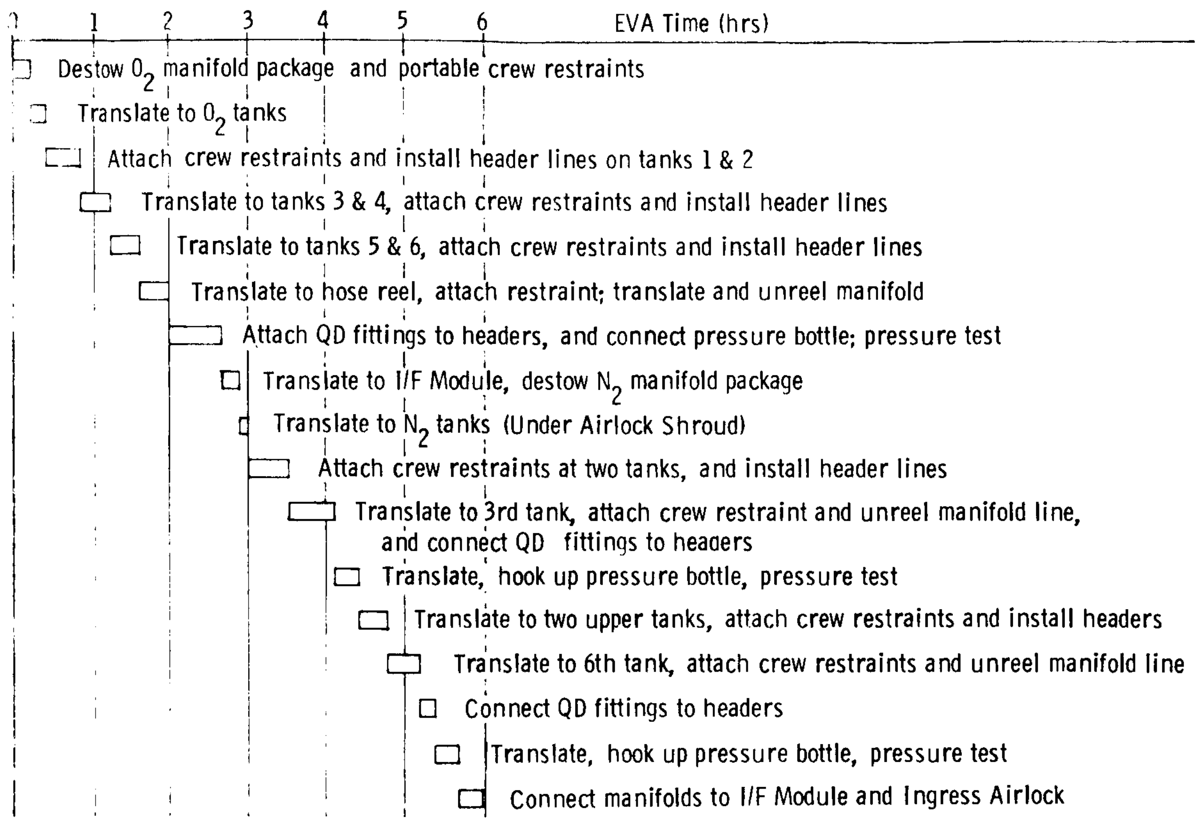


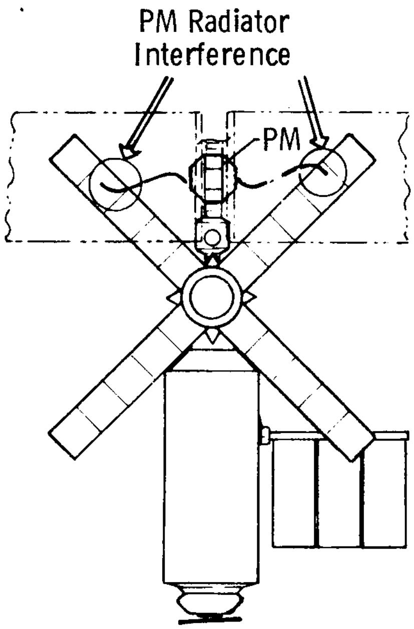
Figure 3.2-29 O_2/N_2 Installation and Test Timeline

3.2.11 ATM Solar Array Wing Retraction

Concept

ATM solar array wings 1 and 2 must be retracted to avoid interference with Power Module radiators when the Power Module is docked to the Interface Module. Figure 3.2-30 shows this interference,plus our concept for retraction.

Requirement: ATM Solar Array Wings 1 & 2 Must Be Retracted To Avoid Interference with Power Module Radiators



Concept:

- Using latch supression tool, manually unlock mechanical lock on each slider of wings 1 & 2
- Pull slider to open limit switches (energizes power bus)
- Electrically retract via C & D panel (80% retraction)
- Manually disconnect drive mechanism
- Fully retract wings and fasten manually using retention strap

Figure 3.2-30 ATM Solar Array Retraction Concept

A kit consisting of latch suppression tools and retention straps is required to perform this task by EVA. The concept involves depressing two latches on each of the two wings, so the slider can be pulled down, opening the limit switches, energizing the drive circuit, electrically retracting the wings by a command from the ATM C&D panel, and securing the wings in place with retention straps. The schematic in Figure 3.2-31 shows the ATM solar array wing deployment circuits which will be used to retract the wings after manually unlocking the sliders and energizing the circuit.

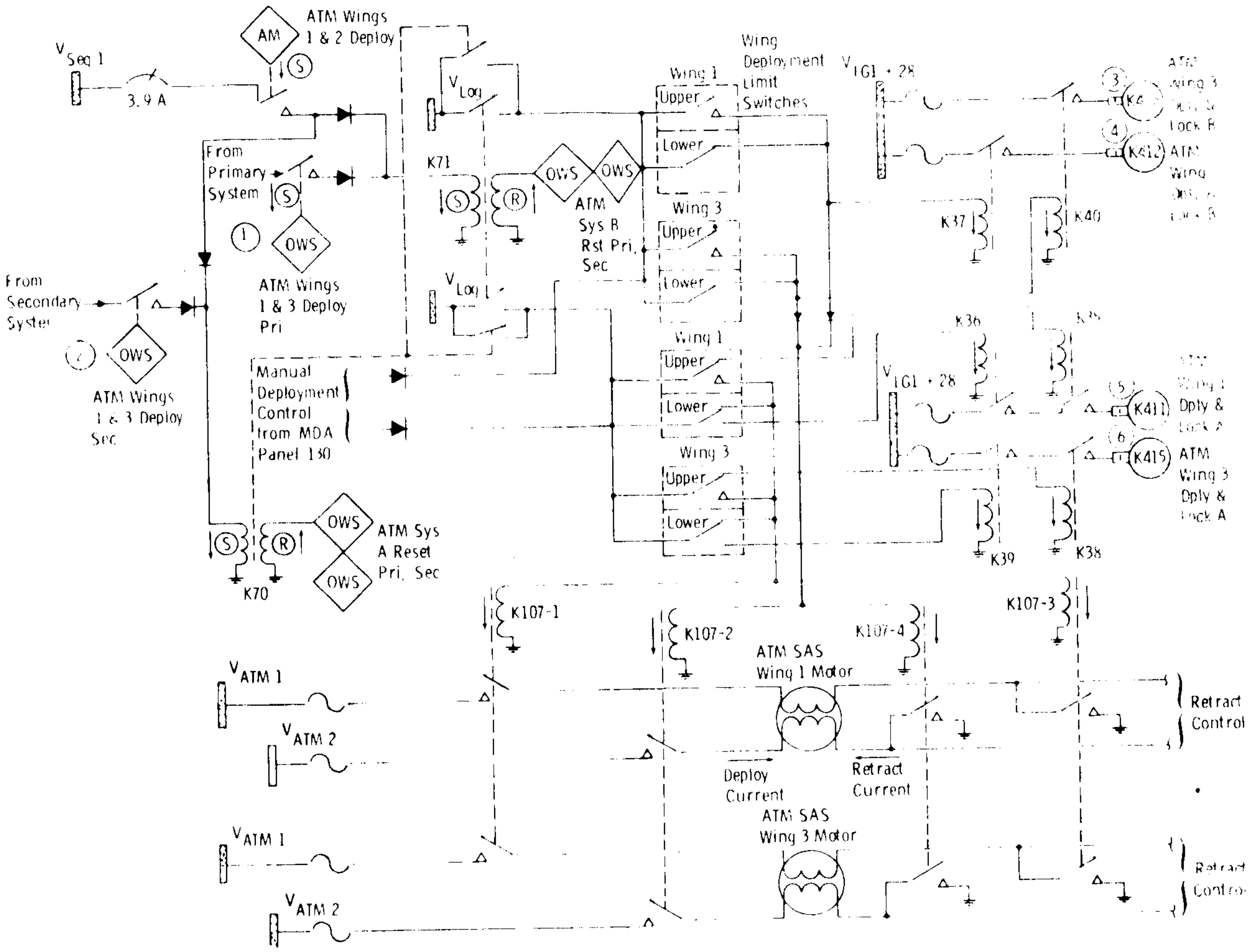


Figure 3.2-31 ATM Solar Array Deployment Circuit

The proposed solar array wing retraction tools and details of the solar array mechanism where the tools are applied are shown in Figure 3.2-32.

The latch suppression tool is inserted between the slider cable and the slider rail near the lower edge of the slider, on both slider rails of each wing. It is hooked over one edge of the rail and when pressed down on the slider latch, snaps its own latching hook over the other rail edge. The slider is then free to move together with the tool, and can be pulled down so

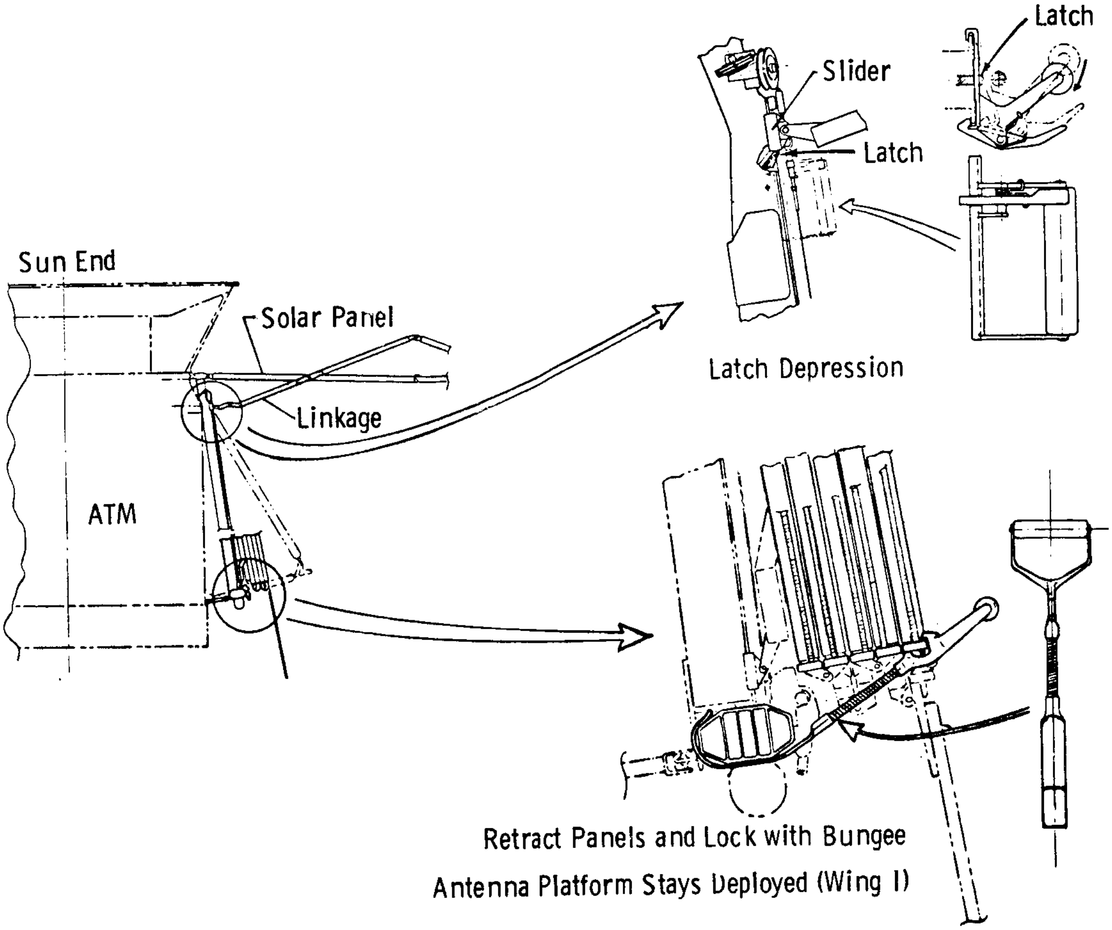


Figure 3.2-32 Solar Array Wing Retraction Tools

the limit switch opens and the circuit is energized. The depression tool is then removed for use on the other wing. Removing the tool allows full retraction of the wing. After the initial operation, the wing is retracted electrically. Retraction in this mode is approximately 80%. The remaining 20% of retraction is accomplished manually by hooking the retention strap over the lower cross beam and pulling on the panels until full retraction is achieved. The other end of the strap near the handle is then hooked over the panel edge to secure the wing in the retracted position. Two latch depression tools are needed for retracting one wing and are reused on the second wing. One retention strap is used for each wing.

Figure 3.2-33 defines discrete tasks involved in retracting the ATM solar wings and the estimated time required to perform these tasks.

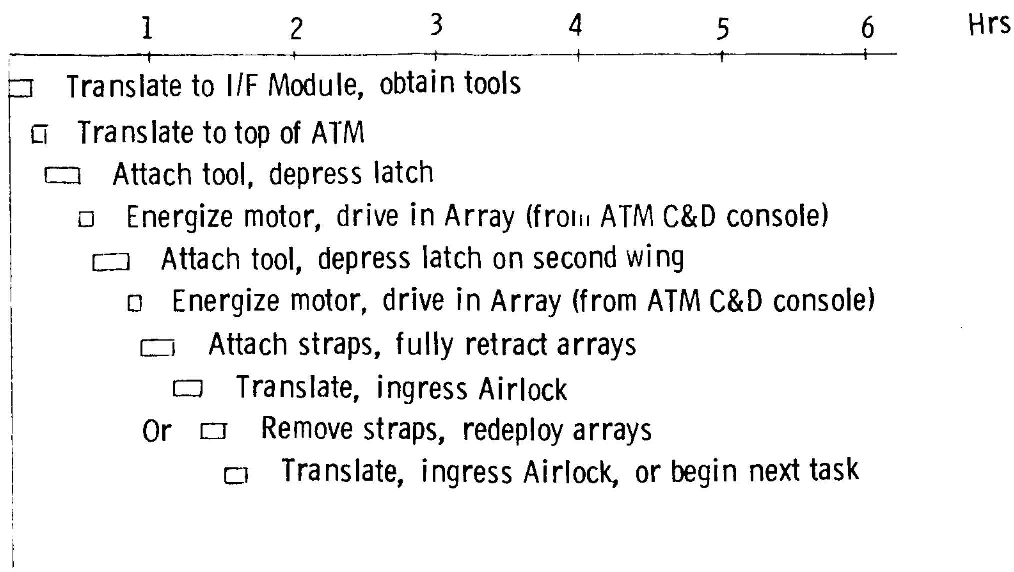


Figure 3.2-33 Timeline for ATM Solar Array Wing Retraction

3.2.12 TACS Resupply

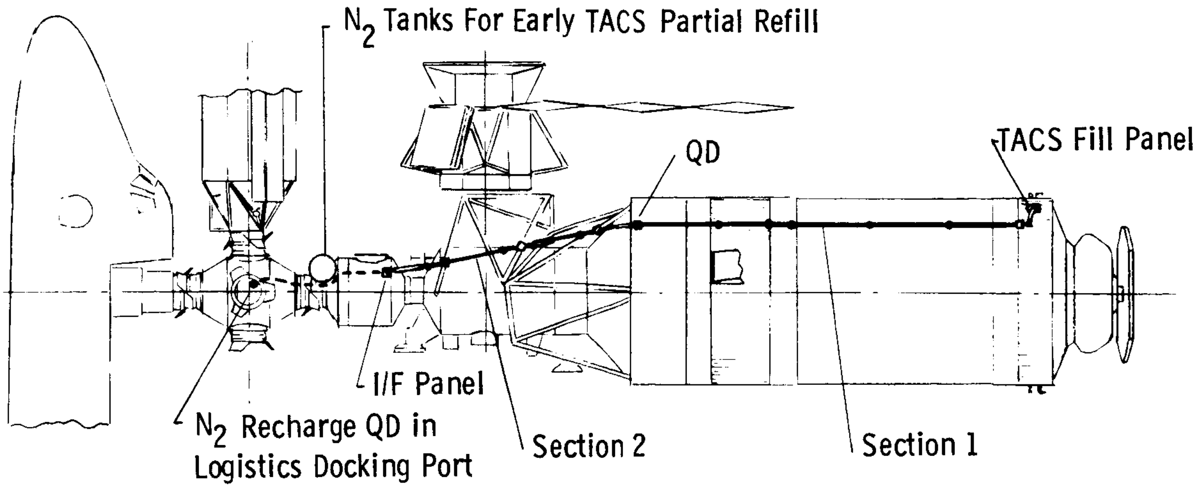
Concept

Because of critical shortage in TACS propellant, the TACS system will be partially filled during the refurbishment flight. This is done to provide control for the next flight. During the refurbishment flight, attitude control will have to be provided by the Orbiter VCS System.

During the refurbishment flight,TACS refill hardware will be installed and TACS tanks partially filled. As shown in Figure 3.2-34, external lines will have to be installed from the Interface Module to the TACS fill panel. Installation of this line will require an EVA. The lines inside the Interface Module are made a permanent installation during construction of the Interface Module. QD connectors are provided between the two sections of the Interface Module, which are connected after the Interface Module docking adapter is docked during the resupply flight.

During the refurbishment flight, TACS propellant is transported in 2 large Skylab N_2 tanks and used to recharge the TACS system with 35,000 lb-sec of impulse capability. This amount of impulse will enable TACS control to be used (if needed) to stabilize the Skylab vehicle during rendezvous and docking for the resupply flight.

When the Orbiter returns during the resupply flight, enough TACS propellant will be carried to recharge the TACS system to correspond to expected usage for 480 man days of a resupply period.



Refurb Flight

- Attach permanent N_2 Transfer lines (Sections 1 & 2)
- Option: Partially fill TACS system (for Stability on Resupply Mission)

  500 lbs N_2 / 35,000 lb-sec } 2 large N_2 tanks

Resupply Flight

- Fill TACS from
  - Logistics Module (Attached to IM)

    or
  - Spacelab Pallets (in Orbiter Bay)

  N_2 per TACS Tank: 70.1 lbs (Impulse = 4500 lb-sec)

  Total N_2: 1543 lbs (Impulse = 99,000 lb-sec)

  Tank Pressure: 3000 psi

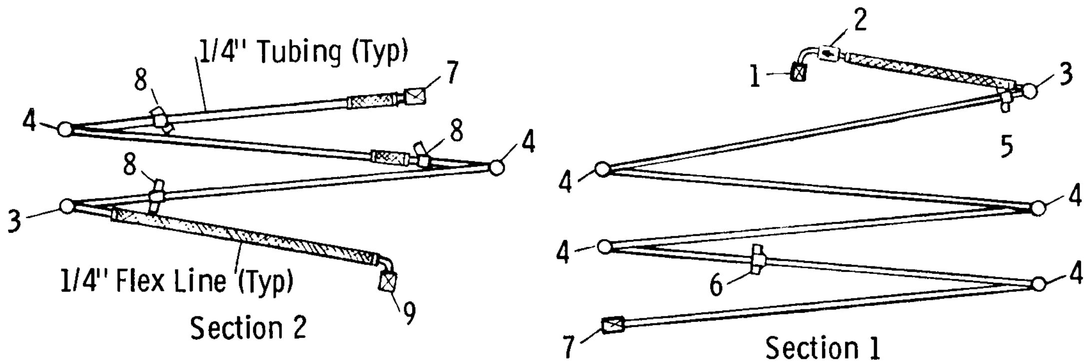
Figure 3.2-34 TACS Resupply Concept

TACS Refurbishment Kit

The TACS refurbishment kit (Figure 3.2-35) consists of two tubing sections connecting resupply tanks to existing TACS tanks on Skylab. The tubing sections come folded in a 9-foot long package which is carried on the outside of the Interface Module (IM) during launch. After the IM is docked to Skylab, an EVA is performed during which the fill line sections are removed from the IM stowage package and installed along the Skylab body.

Section 1 consists of five folded sections nine feet in length with a shorter flexible section. When the sections are extended, rotary joints (Item 4) lock in the extended position giving a rigid line approximately 45-feet long. The line is then fastened to the Skylab OWS using skirt clamps (Items 5 and 6). After connecting the QD's (Item 7), Section 2 is installed in a similar manner, extending from the OWS to the IM.

This section of tubing will be fastened to the deployment assembly trusses using appropriate clamps (Item 8). After the two sections are secure, the ends are connected to the TACS fill panel and IM panel respectively via QDs (Items 1 and 9). Rotary joints (Item 3) and the flex lines allow the freedom to make required adjustments when hooking the lines to the TACS and IM panels. The check valve (Item 2) prevents propellant escaping from the TACS tanks.



1. QD to TACS Fill Port
2. Check Valve
3. Rotary Joint (non-locking)
4. Rotary Joint (Locks in Ext Pos)
5. Skirt Clamp, Fixed
6. Skirt Clamp, Sliding
7. QD Line Connect
8. Strut Clamp, Sliding
9. QD to Interface Module Panel

NOTE: Sections fold compactly into package carried on outside of Interface Module at launch

Equipment List

Description	Size
High-Pressure Foldable Tubes, Section 1 & 2 with 4 QD's, Rotary Joints and Clamps	1/4" I. D. 9 ft Folded Length 80 Ft Length (Total)

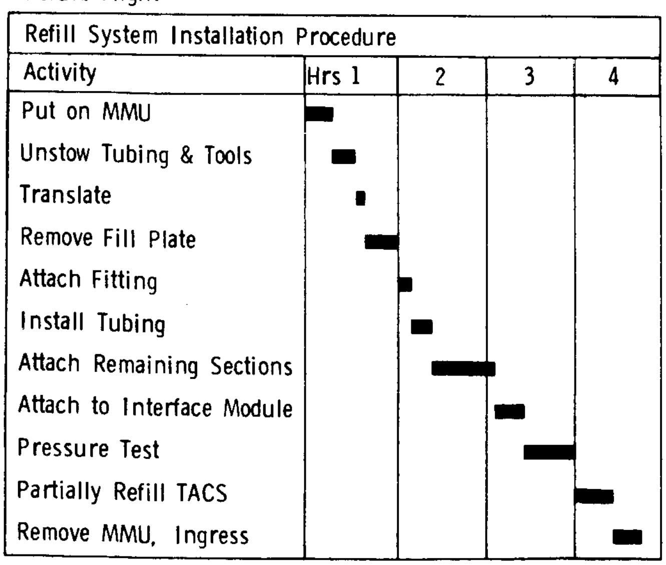
Figure 3.2-35 TACS Refurbishment Kit

TACS Refill Procedure

Figure 3.2-36 shows the TACS refurbishment and resupply procedures. Activity to install hardware during the refurbishment flight requires EVA. Once external lines have been installed, testing of the system and partial refill can be accomplished from within the Interface Module Tunnel because the two refill tanks are mounted on the tunnel. A compressor unit is required on the IM to accomplish the transfer of gas in the initial supply tanks. After these tanks are used for the initial resupply, they can be used as a pumpdown reservoir for the airlock and emergency N_2 supply for shelter requirements.

During the resupply flight, the TACS propellant resupply tanks can be carried on the Logistics Module, which docks to the Interface Module, or the tanks can be carried on a pallet in the Orbiter Bay. The Logistics Module option will allow the TACS resupply activity to be performed IVA since a direct line exists from the Interface Module Docking Port to the TACS refill port. If the resupply tanks are in the Orbiter Bay, then an EVA will be required to connect a line from the tanks to a connector provided on the Interface Module. In either option, there is no differentiation for the N_2 supply between TACS and atmospheric N_2. A control panel in the IM, close to the IM interface panels, will direct the N_2 supply either to TACS or to the N_2 tanks for Skylab pressurization.

Refurb Flight



Resupply Flight

TACS Resupply Procedure
Select TACS Option on Control Panel Connect N_2 Line from LM to IM (IVA, Logistics Module Option) Connect N_2 Line from SM to IM (EVA, Spacelab Module Option) Open Valve on Control Panel in SM or IM Equalize Pressure Start Compressor Transfer N_2 Until 3000 psi Is Reached in TACS Bottles Shut Down Compressor, Close Valve & Disconnect Line If SM Option
Time of Operation - Logistics Module - 1 Hour - Spacelab Module - 3 Hours

Figure 3.2-36 TACS Refill Procedures

3.3 REFURBISHMENT MISSIONS

This section presents the results of an analysis used in defining missions required to refurbish the orbiting Skylab and make it habitable for future space experimentation. The intent is to define the number of missions and durations required to install the kits defined in Section 3.2, to inspect and checkout Skylab Systems/Subsystems, and to provide sufficient resupply consumables for subsequent flights. Various mission options were considered in the analysis. They are compared below from a technical and cost standpoint.

3.3.1 Mission Scenario And Approach

The mission scenarios were prepared to establish the most cost effective refurbishment and resupply flights for preparing

Objectives:

- Define number of refurbishment missions
- Define mission durations
- Define payload weight & length
- Establish transportation costs

Approach:

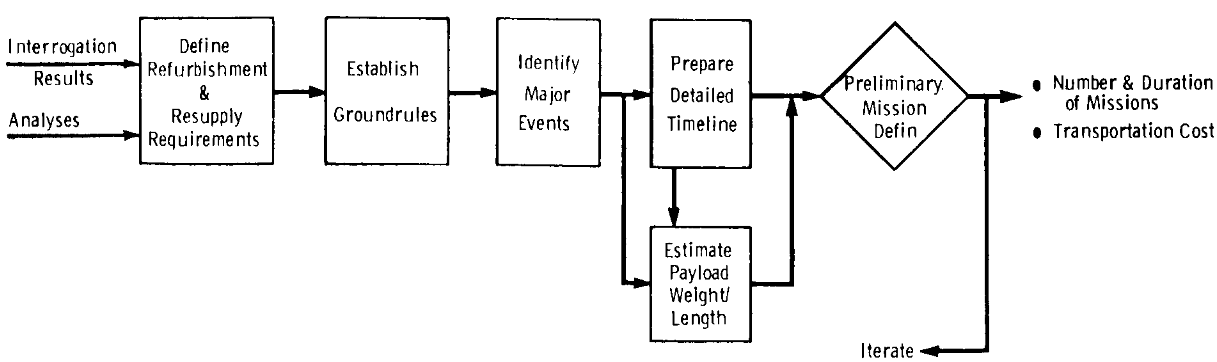


Figure 3.3-1 Mission Scenario and Approach

Skylab for a future operational era. In this scenario the number of missions, their durations, payload sizes and transportation costs were defined. Figure 3.3-1 shows the approach including preparation of refurbishment and resupply requirements, ground rule definition, identification of major events and the time associated with these events, preparation of timelines, estimates of payload weight, length and costs. The process is iterative and needs to be repeated in more detail as the input data become more refined.

The baseline and three optional physical configurations shown in Figure 3.3-2 were considered in the mission analysis. The baseline and Option 1 both included a two-piece interface module approach. The former consisted of two flights to bring the interface module components and refurbishment kits to Skylab in 1982 and 1983, respectively, followed by a logistics flight in 1984. The latter added some resupply capability to the first two flights (utilizing Spacelab hardware) and deferred the logistics flights until 1985.

1982 (Phase II)	1983 (Phase II)	1984 (Phase III 1 & 2)	1985
<u>Baseline</u> Interface Module Adapter, TRS Refurb Kits TACS Replenishment	Interface Module Adapter, Refurb Kits	Power Module Refurb Kits Logistics Module	
<u>Option 1</u> Add Resupply Pallet To Baseline	Add Spacelab Resupply to Second Mission	Power Module Refurb Kits	Logistics Module
<u>Option 2</u> One Piece Interface Module, TRS, Refurb Kits, TACS Replenish- ment		Power Module Refurb Kits Logistics Module	
<u>Option 3</u>	One Piece Inter- face Module, TRS, Refurb Kits, Resupply	Power Module Refurb Kits	Logistics Module

Figure 3.3-2 Refurbishment and Resupply Mission Options Considered

Options 2 and 3 somewhat paralleled the baseline and Option 1, but used a one-piece I/F Module. The first flight of Option 2 in 1982 provided refurbishment, but essentially no resupply. The second Option 2 flight in 1983 provided logistics resupply. Option 3 uses a single flight to deliver the Interface Module and refurbishment kits, and adds resupply. The Interface Module is loaded internally with supplies and supplemented by two Spacelab pallets. These pallets carry water, oxygen and nitrogen. The Option 3 approach allowed for deferral of logistics resupply until 1985. Each of these two options included requirements to complete the installation of kits defined in Section 3.2, system and subsystem checkout, and resupply of consumables for subsequent flights.

3.3.2 Refurbishment Missions Groundrules

As a precursory step to the preparation of time lines, groundrules were generated to help allocate time blocks and to organize the daily activities. Crew activity experience was gathered from the actual events as they occurred in the original Skylab mission, and from planning documents associated with the Orbiter and the Teleoperator Retrieval System. These groundrules are listed below:

1. Initial entry into Skylab will be in a suited mode for visual inspection, assessment of atmosphere, and preliminary subsystem checkout.

2. During Initial Activation, the crew will return to the Orbiter for sleeping and main meals.

3. Crew members will perform presleep activities, eat, and sleep at the same time. For scheduling purposes: presleep activity - 1 hour; sleep - 8 hours; post sleep activity - 1/2 hour; eat - 1 hour.

4. The Interface Tunnel will act as an airlock between the Orbiter and Skylab. For scheduling, two hours will be required to accommodate the prebreathing function.

5. For the first refurbishment mission an option of using the Teleoperator Retrieval System (TRS) will be used for stabilization of Skylab prior to Orbiter docking. The TRS can be used optionally for reboost.

6. The Remote Manipulator System (RMS) will be used to remove the Interface Module Tunnel and I/F Module Docking Adapter from the payload bay and to aid in docking these articles with the Orbiter.

7. Two 2-man EVAs of 6 hours duration are available for Shuttle payloads at no cost. The nominal limit for an EVA is 6 hours.

8. Time estimates are based on Skylab experience, i.e., activities in zero-g take about 2 1/2 times 1-g duration for a short mission, due primarily to the high probability of suffering mild space malaise during first week in orbit.

3.3.3 SKYLAB REFURBISHMENT MISSION SCENARIO - MISSION NO. 1, 1982: TWO-PIECE I/F MODULE

The first Skylab refurbishment mission, illustrated in Figure 3.3-3, carries the Interface Tunnel, TRS and possibly a pallet for resupply. The Orbiter will rendezvous near Skylab and deploy TRS. TRS docks with and stabilizes (and possibly reboosts) Skylab. During this mission Skylab subsystems are inspected, checked out, and refurbished as required. The kits we anticipate for this mission are for refurbishing the coolant loop, communications system, potable water system, waste management system, O_2/N_2 refills, TACS resupply and lighting. Some of the refurbishment activities will be merely to install fixturing in preparation of a later resupply, while others include some resupply. Based on prepared time lines, the mission duration will be approximately 7 days, with an additional 12 hours required for TRS reboost and orbital transfer and rendezvous.

<u>Concept</u>

- Stabilize Skylab with TRS for docking
- Reboost (option only)
- Install Interface Tunnel
- Inspect, sample, refurb systems
- Mission duration 7 days nominal
- Partial Resupply

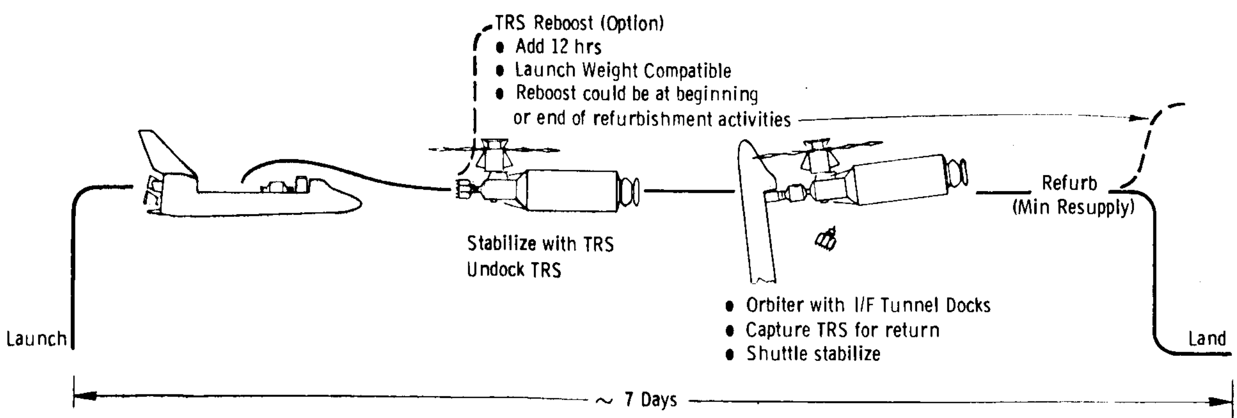


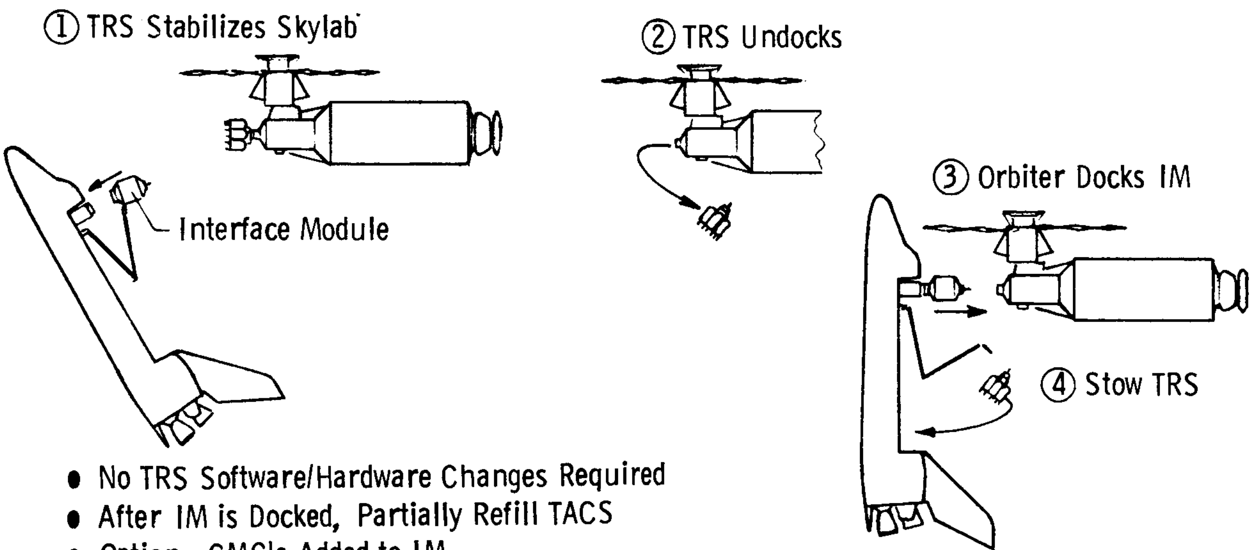
Figure 3.3-3 Skylab Refurbishment Mission Scenario--Mission No. 1, 1982: Two Piece I/F Module (Phase II)

Skylab Reuse and Docking Stabilization concept (Figure 3.3-4) shows the concept for docking and stabilization using the TRS. Docking to the end port of the MDA requires no TRS modification, since this is the docking technique planned for the first Skylab reboost mission. After Stabilization of Skylab, the TRS undocks and is parked on-orbit near Skylab. The Orbiter, with the Interface Module Docking Tunnel attached to its Docking Module then docks with Skylab. This docking concept should be feasible and is our baseline. However, a detailed analysis of the effects of Orbiter thruster infringement on Skylab and the resultant relative motion will be needed. If continuous stabilization of Skylab by TRS during docking is required, then the TRS can be docked to the MDA radial port. Modifications to the autopilot and software may be needed for this concept.

We recommend partial recharge of the TACS tanks on the first mission. This will provide TACS control of Skylab for subsequent missions.

Condition: Assume CMG's/TACS Control Not Available by 1982 - 83

Docking Procedure on Refurb Flight



- No TRS Software/Hardware Changes Required
- After IM is Docked, Partially Refill TACS
- Option: CMG's Added to IM

Subsequent Mission

- Skylab Stabilized with TACS or Optional CMG's on IM
- TRS Not Required

Figure 3.3-4 Skylab Reuse Stabilization and Docking Concept

Various data sources were researched to prepare detailed timelines for mission events from lift-off to landing. The timelines were generated in a logical fashion by initially constructing a typical crew day, which illustrated the major repetitious daily activities as a preliminary format. (Reference, JSC-07896, Shuttle Systems Baseline Mission, Volume II, Mission 2, Rev. 2, Aug. 1975). The times for major Shuttle activities were also derived from this document.

The next step taken was to determine the sequence of events from launch to docking with Skylab. The elapsed times for the TRS activities were researched and included in the first day, including the orbital transfers, rendezvous, checkout, transfer to Skylab and docking times. (Reference, TRS-CM04, Space Shuttle Program Teleoperator Retrieval System, Skylab Boost Mission Flight Operations, (Preliminary), March 1978). For the first TRS mission the time for these activities is assumed to be approximately four days, due to a requirement to be able to launch on any day. In our study we assumed the launch date can be selected to optimize the orbital changes required to rendezvous with Skylab, thus reducing this time to approximately one day.

We further identified the events required to be performed on Skylab for checking out and activating the existing onboard systems. These systems and the elapsed times were identified from existing Skylab Documentation. (References MSC 04727, Skylab Operations Handbook, Volume I, Systems Descriptions, 24 Jan 1972 and MSFC 25M00700, Skylab Mission Events (SL-1/2, SL-3, and SL-4), February 1974). The times for planned extra vehicular activities were derived by using Shuttle planning documents for the preparatory events, maximum time on EVA, and the post EVA times. (Reference, JSC-10615, Shuttle EVA Description and Design Criteria, May 1976). The actual times for the EVA were based on detailed timelines we prepared for each refurbishment activity.

All these identified events were inserted into the available crew timeline blocks in a serial fashion to determine the total mission duration. Since a four man crew was assumed, selected events were then combined as parallel operations to derive contingency times. Separate timelines were prepared with and without reboost; the difference was twelve hours. Results of the analysis, including major events and their associated times are summarized in Figure 3.3-5.

Mission Day 1	Boost -- Orbital Coast -- Rendezvous
Mission Day 2	Dock -- Suited C/O of I/F Tunnel & Skylab, Obtain Samples
Mission Day 3	Complete AM/MDA Subsystem C/O -- Recharge Coolant Loop
Mission Day 4	Complete OWS Subsystem C/O -- EVA: TACS Resupply, Inspection
Mission Day 5	EVA, O_2 / N_2 Manifold Installation
Mission Day 6	Experiment C/O -- Equipment Transfer
Mission Day 7	Deactivation -- Undock -- Land

Timeline Mission Summary

Total Time	168 hrs (7 days)
Contingency Time Available	20%
Add for Reboost	12 hrs

Figure 3.3-5 Refurbishment Mission No. 1--Timeline Summary

Once having the mission duration, the entire payload weight and center of gravity can be calculated. The total payload weight is dependent on certain Orbiter payload chargeable equipment, which itself varies with payload requirements and mission length. Payload chargeable equipment will be discussed in more detail later.

The refurbishment mission payload arrangement (Figure 3.3-6) satisfies the first mission of baseline and Option 1 configurations. The baseline configuration consists of the Orbiter Docking Module, TRS, and Interface Module Tunnel. The configuration is altered by the addition of a resupply pallet for Option 1. The lower portion (Figure 3.3-6) illustrates the allowable payload center of gravity cargo bay envelope. Each configuration is seen to be within these limits.
For the first mission, payload weight and length (Figure 3.3-7) were calculated to determine transportation costs, based upon the methods of the reference document (Reference JSC-11802, Transportation System Reimbursement Guide, February 1978). For partial payloads, this guide utilizes the maximum weight or length percentage of the allowable limits to determine a factor for computing launch costs. Document costs in 1975 dollars

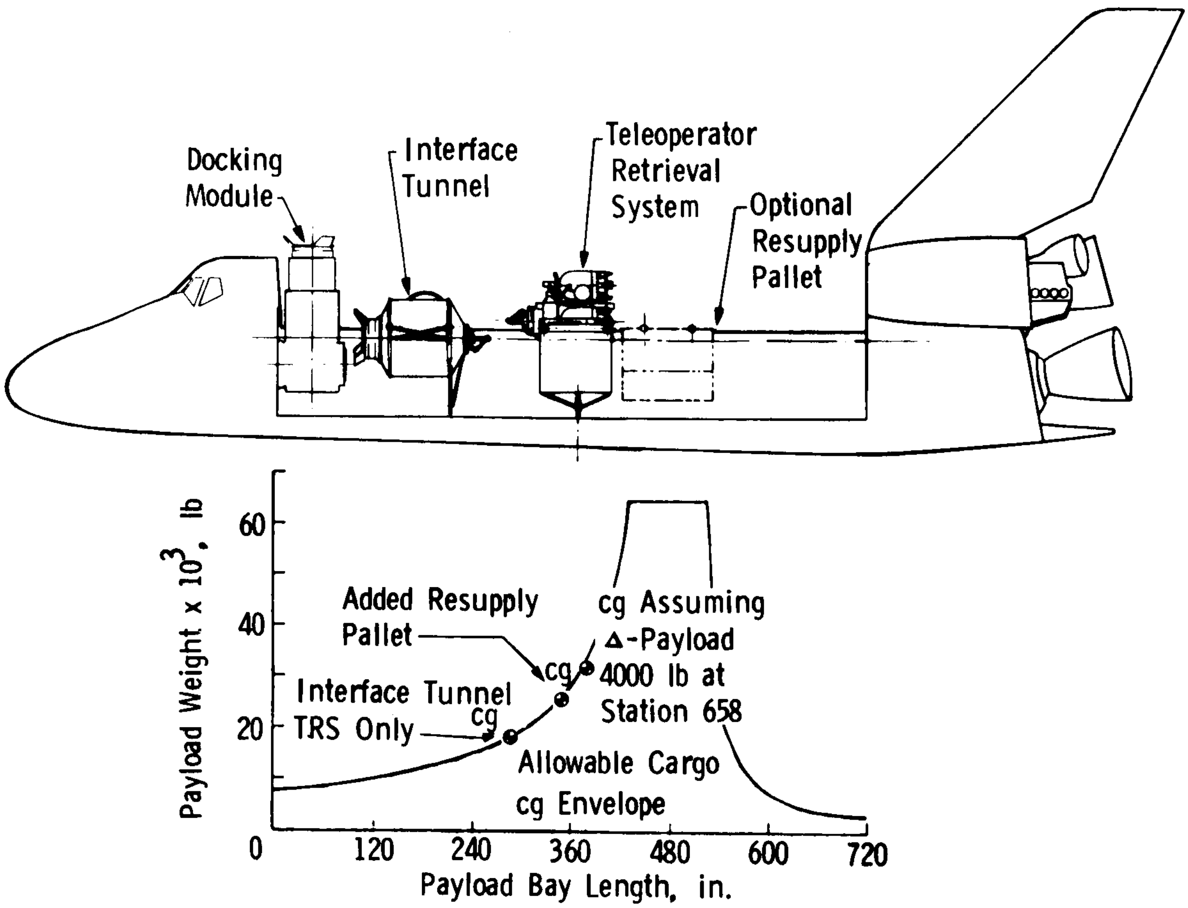


Figure 3.3-6 Skylab Refurbishment Mission No. 1--Payload Arrangement and Center of Gravity

were escalated to 1978 dollars by using a 1.302 inflation multiplier. Computations of cost illustrate the basic option, and additional costs for adding a single resupply pallet and the reboost. The costs contain fees for using the Orbiter Docking Module, EPS Kits, Spacelab Pallets, time above seven days, and for the basic launch.

Payload Item	Weight (Lbs) Ascent	Reentry	Envelope (Ft) Volume (ft^3)	% of Total Payload	Transportation Cost
Interface Tunnel	2,966	0	15D x 14.2L 322		
Docking Module	3,183	3,183	12.5H x 7D 481		
Teleoperator Retrieval System (TRS)	13,000	6,849	10.6H x 10.6W x 10.5L 249		
Pallet (Option)	8,468	6,395	9.9L		
P/L Chargeable	1,800	856	Included Above		
TOTALS					
W/O Pallet	19,149	10,888	34.8	58	18.23
W/Pallet/TRS Reboost	29,417	17,283	44.9	75	24.06

Figure 3.3-7 Mission No. 1--Payload Weight, Length and Transportation Cost Summary

The second planned refurbishment flight (Figure 3.3-8) delivers the second of the two-piece Interface Module, the Docking Adapter and as an option -- resupplies Skylab consumables. The Docking Adapter attaches to the Orbiter and provides docking ports for payloads and the Power Module. Several resupply alternates were available. This one assumed use of a Spacelab module plus pallet. Remaining refurbishment kits were assumed to be installed during this mission. These kits include O_2/N_2 recharge, TACS resupply, Waste Management System Verification, Potable Water Transfer, ATM array folding, and Power Transfer from Power Module Interface to the ATM.

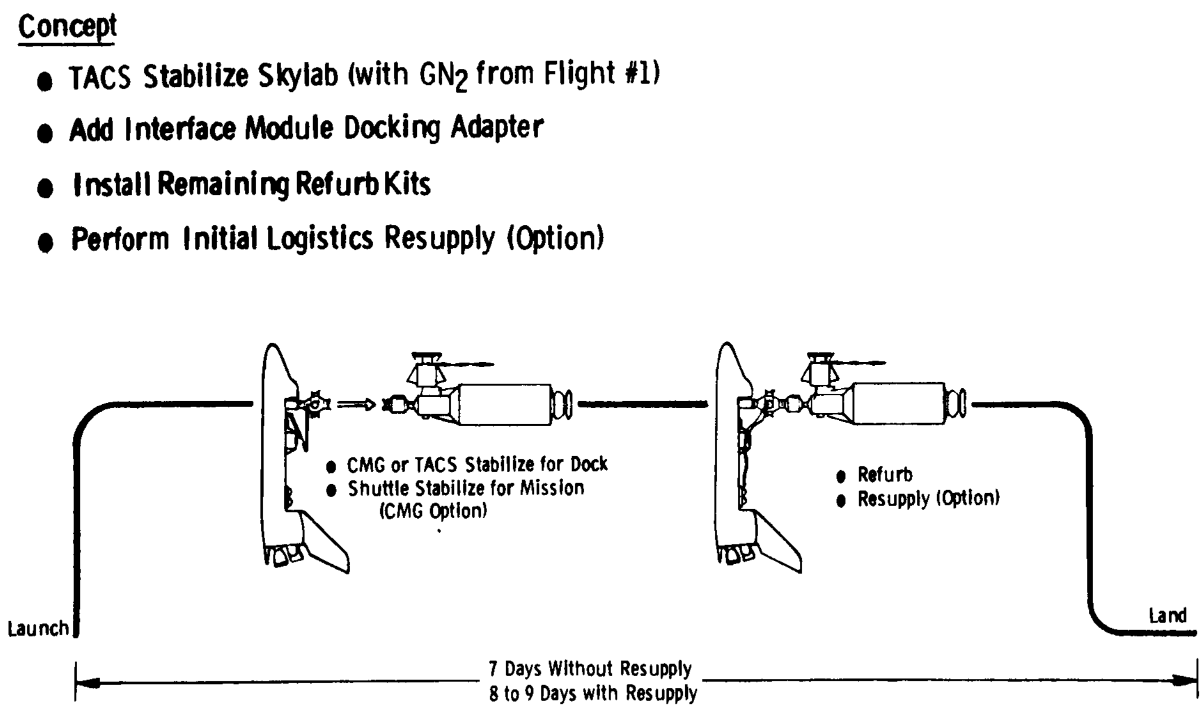


Figure 3.3-8 Skylab Refurbishment Mission Scenario--Mission No. 2, 1983 (Phase II)

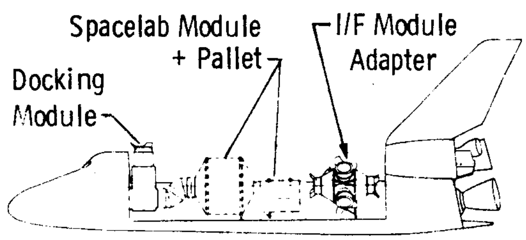
The second refurbishment mission timeline (Figure 3.3-9) required 7 days for completing the refurbishment activities begun on the first mission. By adding the Spacelab and pallet, mission duration was increased to 8.3 days, with the extra time going into offloading the consumables into Skylab. The approach used for preparing both the timeline and the contingency percentages was similar to the method described above.

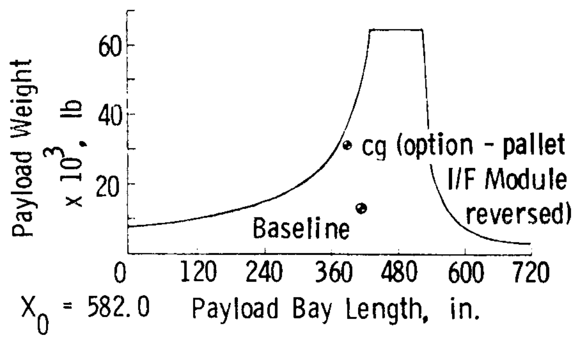
Mission Day 1	Boost -- Orbital Coast -- Rendezvous
Mission Day 2	Dock -- Suited C/O of I/F Adapter/Tunnel & Skylab
Mission Day 3	Complete Activation of AM/MDA -- Connect TACS & O_2 / N_2 Internal Lines
Mission Day 4	Complete Activation of OWS -- EVA: ATM Array Fold, Power Transfer Cable Camera Retrieve
Mission Day 5	Complete EVA -- Waste Management Kit Installation
Mission Day 6	Waste Management Kit Installation -- Experiment C/O
Mission Day 7	Equipment Transfer -- Deactivation -- Undock -- Land

Timeline Mission Summary

Without Resupply	168 hrs (7 days)
Contingency	12%
With Resupply (Option)	200 hrs (8.34 days)
Contingency	17%

Figure 3.3-9 Refurbishment Mission No. 2--Timeline Summary





Payload Item	Weight, lb		Envelope, ft	% of Total Payload	Transportation Costs, $M
	Ascent	Reentry	Volume, ft^3		
Interface Module	7261	0	15D x 16.3L / 404		
Shuttle Docking Module	3183	3183	12.5 H x 70 / 481		
P/L Chargeable	1841	930			
Total Without Resupply	12285	4113	23.3	39%	14.94
Option Spacelab Module + Pallet	20544	14455	15D x 32.1L		
Total With Resupply	32829	18568	60	100%	31.49

Figure 3.3-10 Mission No. 2--Payload Length, Weight and Cost Summary

Figure 3.3-10 illustrates the configuration (i.e., locations, payload weight, length) and cost for the baseline and Option 1 second mission. The center of gravity was within the allowable cargo bay envelope for each configuration. The baseline configuration had a partial payload and thus a lower cost. Option 1, including the Spacelab hardware, had higher costs, primarily caused by the increased launch weight/length, the additional resupply operations activities, plus added payload chargeable items and operations costs for the time exceeding 7 days on orbit.

Skylab Refurbishment Mission Scenario -- One-Piece I/F Module (1982 or 1983)

The refurbishment mission scenario (Figure 3.3-11) highlights events of Options 2 and 3 using the one-piece Interface Module with and without resupply, respectively. For each case the use of TRS for reboost was an additional option. In either of these missions all of the necessary refurbishment carried out on the

Concept

- Stabilize Skylab with TRS for Docking
- Reboost (Option only)
- Install one piece Interface Module
- Inspect, Sample, and Refurbish Systems
- Resupply (Option)

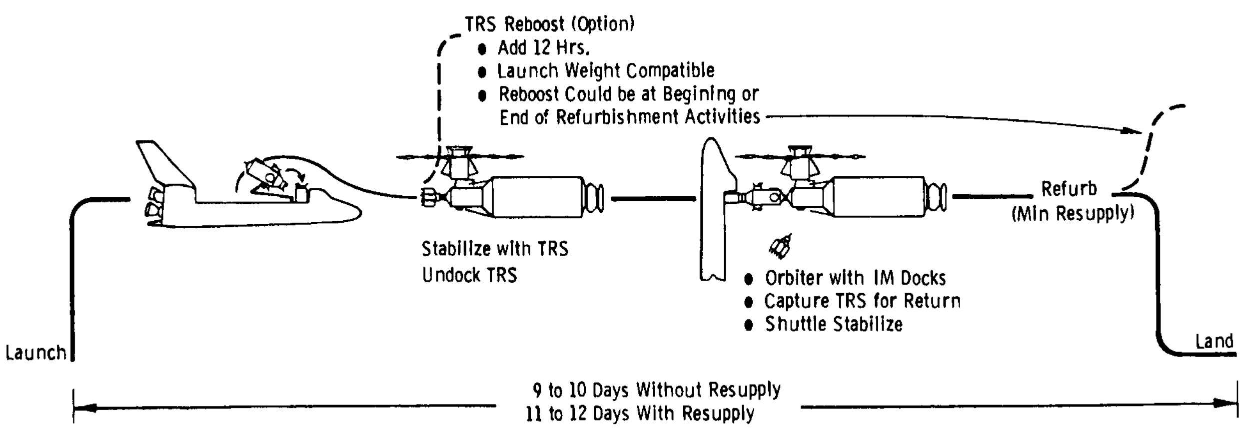


Figure 3.3-11 Skylab Refurbishment Mission Scenario: One Piece I/F Module (1982 or 1983)

baseline Missions 1 and 2 can be completed with a slight increase in duration. Without resupply, the mission lasted 9 to 10 days; with resupply it was 11 to 12 days in length. This mission can occur early 1982 or the latter part of 1983. The 1982 mission provides early refurbishment, control and operation of Skylab (for example, operation of ATM solar instruments). Refurbishment costs can be deferred by delaying the flight until shortly before docking the Power Module in January of 1984.

Timeline requirements for the one-piece Interface Module flight are illustrated in Figure 3.3-12. The timeline shows the mission highlights for each day, including rendezvous, docking, checkout and refurbishment of Skylab systems, resupply, final closeout procedures and landing. Contingency percentages were again derived by combining events which were initially defined serially. Note that three EVAs are required. We assumed that two would be performed by one pair of astronauts and one by the other. Splitting the EVA activities reduces the physical demand on the crew.

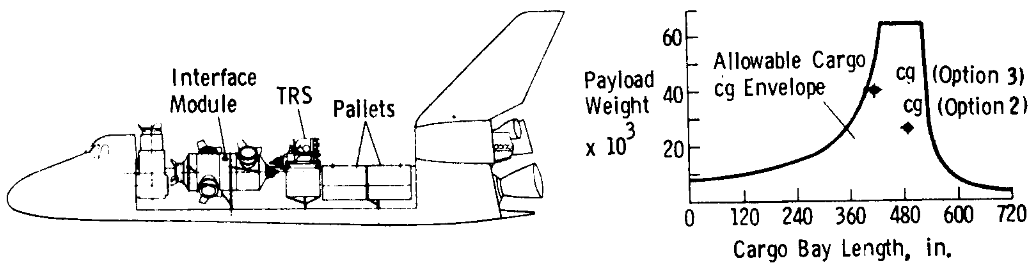
Mission Day		
	1	Boost -- Orbital Coast -- Rendezvous
	2	Dock -- Preliminary Suited C/O of I/F Module and Skylab
	3	Complete AM/MDA Subsystem C/O -- Coolant Loop Recharge
	4	Complete OWS Subsystem C/O -- Unload Supplies From I/F Module
	5	EVA -- TACS Resupply, Inspection
	6	EVA: O_2 / N_2 Manifold Install -- Internal Power Transfer Cables
	7	Waste Management Kit Install -- Experiment C/O
	8	EVA: Communications Cables, O_2, N_2, H_2O Hookups
	9	EVA: ATM Array Fold, Power Transfer Cables -- Transfer TACS Transfer O_2, N_2, H_2O (Option)
	10	Equipment Transfer -- Reentry Procedure -- Deactivate
	11	Deactivate -- Undock -- Land

Timeline Mission Summary

Total Time (2 Pallets + Resupply)	248.5 Hrs (11.35 days)
Contingency	19%
Total Time (W/O Pallets, W/O Resupply)	221 Hrs (9.2 days)
Contingency	21%

Figure 3.3-12 Single I/F Module Mission Timeline Summary

The One Piece Interface Module Options 2 and 3 payload characteristics are presented in Figure 3.3-13. Option 2, without resupply, contains the Docking Module, I/F Module and TRS. Analysis has shown that the center of gravity can be compatible with Orbiter constraints. Examining the transportation costs of the two options yields an interesting conclusion: Addition of two resupply pallets can be accomplished with a reasonable incremental cost for the benefits derived. A significant initial resupply (approximately 320 man days) can be provided by loading the Interface Module and the two pallets.



Payload Item	Weight, Lb		Payload Envelope, ft / Volume, ft^3	% of Total Payload	Transportation Cost, $M
	Ascent	Reentry			
Interface Module	8637 2513 *	0	15D x 23.5L		
Docking Adapter	3183	3183	12.5H x 7D 481		
Teleoperator Retrieval System (TRS)	13000	6849	10.6H x 10.6W x 10.56		
Pallets (2)	16890	11621	19.8L		
Payload-Chargeable	2119	1122	Included Above		
TOTALS					
W/O Pallets	26939	11154	40	66	21.76
W/Pallets	46342	22775	60	100	26.97

* Resupply

Figure 3.3-13 Weight Length, and Transportation Cost--One Piece I/F Module + Resupply

Weight, length and transportation cost data used in the previous Figures (3.3-7, 3.3-10 and 3.3-13) include payload chargeable items. These items, defined in the Shuttle Users Guide and the Space Transportation System Reimbursement Guide, are required for functions such as Shuttle docking, mission extension beyond seven days, and additional EVAs (beyond the two EVA baseline). Applicable payload chargeable items are shown in Figure 3.3-14.

Mission	1st Refurb		2nd Refurb		Single Refurb	
Duration	7.21 Days		8.34 Days		9.21 Days	
	Ascent	Reentry	Ascent	Reentry	Ascent	Reentry
EPS Kits	1,632	759	1,632	759	1,632	759
Atmospheric Revitalization System(O_2 + Tankage, N_2 + Tankage, LiOH Canisters, Waste Water Tank)	163	97	187	171	213	185
Crew, Equip, Food	5	--	22	--	35	--
TOTALS	1,800	856	1,841	930	1,880	944

Figure 3.3-14 Payload Chargeable Items--Weight (lbs)

3.3.4 Mission Analysis Summary & Conclusions

Results of the refurbishment mission option study are summarized in Figure 3.3-15, showing mission duration, percentage of use of the payload bay, and transportation costs for each option. Costs shown relate to transportation and payload chargeable items plus operations costs for time in excess of seven days. Note that the baseline (the two-piece interface module case) and Option 2 do not include resupply, while the other cases do.

Launch Date	Description of Payload Options	Duration (Days)	% of The Payload Bay	Transportation Cost $M
	Baseline			
1982	I/F Module Tunnel, TRS, Refurb Kits, TACS Replenishment	7.2	58	18.23
1983	I/F Module Adapter, Refurb Kits	7.0	39	14.94
	Option 1			
1982	Add Resupply Pallet to Baseline	7.2	75	24.06
1983	Add Spacelab Resupply to Baseline	8.3	100	31.49
	Option 2			
1982	One Piece I/F Module, TRS, Refurb Kits, TACS Replenishment	9.2	66	21.76
	Option 3			
1983	Add Resupply to Option 2	11.3	100	26.97

Figure 3.3-15 Summary of Refurbishment Mission Options

The One-Piece Interface Module cases result in lowest transportation costs, since a single flight is needed. The One-Piece Interface Module with resupply is particularly attractive. By loading the module internally with resupply items and adding two pallets for gases and water, approximately 320 man-days of initial resupply can be provided. Transportation costs are $5.2 million compared to $22.4 million using a Spacelab module plus pallets to deliver the same quantity of resupply. Trusses inside the Interface Module used to secure the resupply items will be reused later to add hardware such as the Ku Band communications electronics and to stow shelter provisions.

Refurbishment kits identified to date, TRS stabilization (and, if necessary reboost), partial TACS resupply, and initial resupply can all be flown and installed/operated during a single mission. The duration extends past the nominal seven days, but will be within Shuttle capability, (Reference JSC-07700, Space Shuttle Accommodations Handbook, Volume XIV). Existing GN_2 tanks are mounted on the Interface Module to resupply the TACS. These tanks can then be used to store GN_2 for crew shelter in Phase IV of the Reuse Program.

3.4 RESUPPLY (LOGISTICS)

Operation of Skylab during Phases III and IV will require periodic resupply of consumables and update/expansion of onboard systems. In this section, resupply quantities are defined and two resupply alternatives are compared, 1) use of a Spacelab on a rental, minimum modification basis, and 2) use of a dedicated logistics module. An additional case is shown for initial resupply: loading the Interface Module with resupply items and delivering these to the Cluster during a refurbishment mission.

The following ground rules were applied to resupply:

1) Resupply quantities and design will conform to Shuttle and Spacelab constraints where applicable. In the latter, Spacelab internal racks and cargo bay pallets will be unscarred and loaded per the Payload Accommodations Handbook.

2) On orbit atmospheric O_2 and N_2 will be provided from Skylab through the Interface Module. Fans and ducting will be provided in the resupply module for air ciculation.

3) Skylab O_2 and N_2 tanks are available GFE.

Resupply requirements for Skylab are based on metabolic requirements, Skylab actual usage over 504 man-days of operation, and Skylab constraints such as food locker size, freezer availability, and stowage locker size. Table 3.4-1 lists requirements for resupplying Skylab. These quantities form the basis for sizing the Logistics Module and Use of Spacelab for resupply.

Table 3.4-1 Skylab Resupply Requirements

O_2 / N_2, FOOD, WATER, CLOTHING

O_2	.84	Kg/Man-Day	Metabolic
	1.68	Kg/Day	Leakage, mole sieve, etc.
N_2	.905	Kg/Day	Leakage, mole sieve, etc.
N_2 / TACS	.425	Kg/Man-Day	
Ambient Food	1.51	Kg/Man-Day	Less frozen food use rate
Frozen Food	114.3	Kg	Limited by 5 freezers on board Skylab
Water	3.4	Kg/Man-Day	Metabolic
	19.95	Kg	System start and bleed
	1.45	Kg/Man-Day	Hygiene and waste management
	4.99	Kg	System bleed
Clothing	.47	Kg/Man-Day	

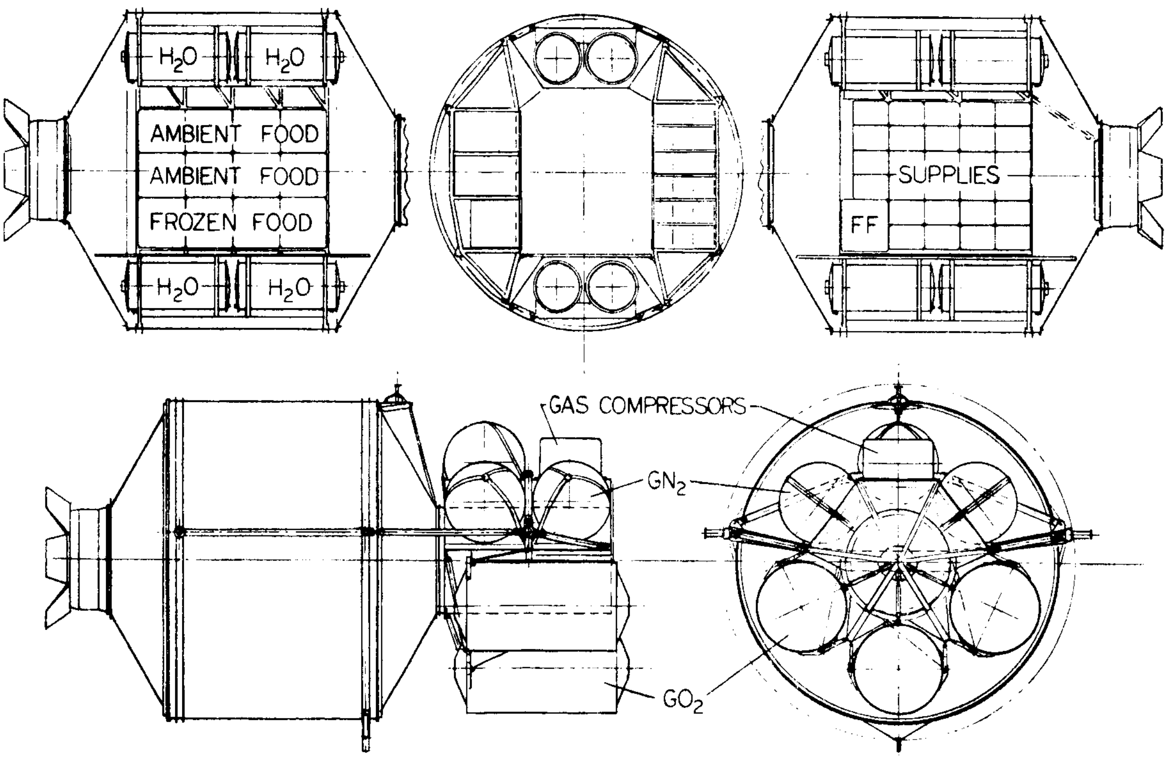
HYGIENE AND WASTE MANAGEMENT

Supplies	Use Rate Per Man-Day	Unit Mass (Kg)	Volume (M^3)
Wet Wipes	.014 Box	.25*	
Utility Wipes	.045 Box	.25*	
Biocide Wipes	.006 Box	.25*	
General Purpose Tissues	.022 Box	.25*	4.77×10^{-3}
Towels	.611 Towel	.116	
Wash Cloths	1.284 Cloth	.037	
Trash Bags	.488 Bag	.318	
Disposal Bags	.378 Bag	.34	5.9×10^{-4}
Urine Disposal Bags	.405 Bag	.34	
Fecal Collection Bags	.744 Bag	.10	
Vacuum Cleaner Bags	.050 Bag	.15*	
Plenum Bags	.0284 Bag	.80*	

* Estimated Unit Weight

3.4.1 Logistics Module

The Logistics Module is based on a Spacelab type design, but is a new structure for two reasons 1) extensive structural modifications will be needed to obtain the higher density cargo loading and 2) cost comparisons between building a new structure and buying a Spacelab structure and modifying it showed the new structure to be less expensive. Our baseline Logistics Module is shown in Figure 3.4-1. This module is equivalent to a single Spacelab module with a cylindrical trailer for mounting oxygen and nitrogen tanks used to resupply atmospheric gasses and TACS N_2 gas. The gas compressors are located in a canister mounted on this structure.



Capability of This Configuration: 480 Man-Days

Figure 3.4-1 Logistics Module

Skylab resupply consumables loaded inside the module consist of ambient food packages, 5 frozen food packs (insulated), 8 water tanks, and 84 one-cubic-foot packs of hygiene, waste management, and crew supplies sized to fit in the original Skylab storage locations.

The module has a shuttle docking mechanism on the forward end and a RMS grapple fitting allowing removal from and insertion into the shuttle payload bay by the remote manipulator arm.

Gasses and water are pumped into the Skylab tanks from fixed installation logistics module tanks. A control panel is provided on the module for pumping gas and water.

The module carries 480 man-days of resupply, based on original Skylab usage rates. Calculations were made for the equivalent of a Spacelab long module plus a longer trailer. This can carry 640 man-days of resupply. However, the configuration was less efficient in terms of man-days of resupply per unit of weight. (480 man-days required 56% of launch weight - 640 days required 81.5%). There may be a middle ground between the two modules, however the shorter module delivers significant supply quantities and allows payload related supplies/instruments to be carried on the same flight.

The baseline Logistics Module carries supplies shown in Table 3.4-2. The three Skylab oxygen tanks contain 1118.5 kg of useable oxygen. This is equivalent to 480 man-days supply based on the actual Skylab use rate of 2.323 kg per man-day.

Five Skylab nitrogen tanks are fitted to the module to supply environmental nitrogen and TACS resupply. Nominal TACS use rate of 0.425 kg/man-day is based on Skylab day 15 through 270. Environmental nitrogen use rate is based on Skylab actual use.

The frozen food is limited by the five Skylab freezers and the ambient food is equivalent to seven Skylab food lockers.

The Logistics Module is removed from the payload bay using the Remote Manipulator System docked to the Interface Module. It can be unloaded immediately or used as longer term pantry. This latter use is attractive since internal supplies are unloaded when needed and trash returned to the Module for ground based disposal. The Logistics Module can also provide shelter volume and consumables for Phase IV operations intended by the Shuttle. Figure 3.4-2 shows the Logistics Module docked to the cluster

Table 3.4-2 Logistics Module 480 Man-Day Resupply Capability

Environmental Control and TACS

0_2	Capacity	1118.55 Kg (Useable)
3 Skylab Tanks	Usage Rate (Skylab)	2.323 Kg / Man-Day
	Support Capability	481.5 Man-Days
N_2	Capacity	498.95 Kg (Useable)
5 Skylab Tanks	ECS Usage Rate (Skylab)	0.395 Kg/Man-Day
	TACS Usage Rate (Skylab)	0.425 Kg/Man-Day
	Support Capability	608 Man-Day

Food

Frozen	Capacity 5 Freezers	114.3 Kg
Ambient	Capacity 7 Food Lockers	631.8 Kg
	Useage Rate	1.51 Kg/Man-Day
	Support Capability	494 Man-Days

Hygiene and Waste Management

	Items	Stowage Volume (M^3)
Wet Wipes	7 Boxes	2.29
Utility Wipes	22 Boxes	
Biocide Wipes	3 Boxes	
General Purpose Tissues	11 Boxes	
Towels	294	
Wash Cloths	617	
Trash Bags	235	0.284
Disposal Bags	182	
Urine Disposal Bags	195	
Fecal Collection Bags	357	
Vacuum Cleaner Bags	24	
Plenum Bags	14	
Personal Hygiene Kit	5	0.0165

Clothing

	Item	Stowage Volume (M^3)
28-Day Clothing Module	18	.454
Constant Wear Garmet	24	.079
Misc. Clothing		.067

on a two-piece Interface Module. We have also defined Interface Module configurations which allow docking the Logistics Module at Skylab pressure (see Section 4.1 below).

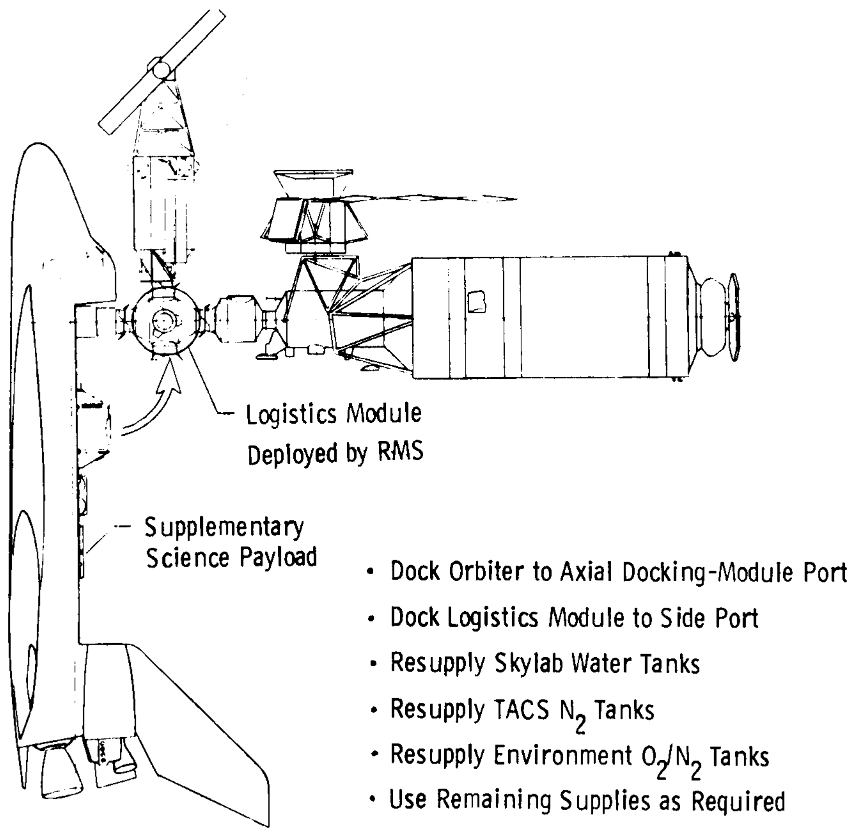


Figure 3.4-2 On-Orbit Operations, Logistics Module Resupply

Logistics Module mass is summarized in Table 3.4-3. The dry weight or return Orbiter payload mass of 8805 Kg represents 61 percent of the shuttle return capability. The gross weight of 14463 Kg represents 56 percent of the Shuttle ascent load capability.

Table 3.4-3 Logistics Module Mass Properties

	Mass (Kg)		
Structure	2,528		
GO_2 Tanks (3)	2,857		
GO_2 Tank Supports	195		
GN_2 Tanks	890		
Feedlines	91		
H_2O Tanks (8)	816		
Supply Racks	248		
Grapple Fitting	6		
Compressors	40		
Packaging	130		
Docking Mechanism	422		
Contingency	580		
Dry Weight	8,805	(19,442 lb)	Return Payload
Food - Ambient	722		
Frozen	114		
Water	2,400		
GO_2	1,274		
GN_2	570		
WMC & Hygiene Supplies	216		
Crew Supplies	362		
Gross Weight	14,463	(31,885 lb)	Ascent Payload

3.4.2 Spacelab Resupply

Spacelab modules and pallets can be combined for resupply. In this analysis we assumed the Spacelab would be rented and would not be scarred in carrying resupply items. Use of the Spacelab in this way requires that the load carrying constraints from the Payload Accommodations Handbook be observed (shown in Table 3.4-4). Transport of Skylab supplies in Spacelab requires 1) adapting structure for the internal standard racks and 2) trusses to mount oxygen, nitrogen, and water tanks to the pallets.

Table 3.4-4 Spacelab Logistics Resupply: Capability/Constraints

Load Carrying Capability		Short Module	Long Module
Module	- Along Side Walls (Rack Location)	634 Kg/m Per side	634 Kg/m Per Side
	- At Overhead Structure	100 Kg/m Per Side	100 Kg/m Per Side
	- At Center Aisle	300 Kg/m	300 Kg/m
	- At Aft-End Cone	798 Kg/m	298 Kg
	- At Subfloor	--	533 Kg
	TOTAL	2900 Kg	6380 Kg
	Subfloor Provision Only		
		Without Igloo	With Igloo
Pallet	- Single Pallet Segment	3130 Kg	3020 Kg
	- Two Segment Train	5040 Kg	5160 Kg
	- Three Segment Train	5060 Kg	5180 Kg

Using Spacelab capability/constraints, various Spacelab combinations were evaluated to see how many man-days of resupply could be carried. The results, including the percentage of the Orbiter cargo bay and resulting transportation costs, are shown in Table 3.4-5. A surprising result is shown: A short module (SM) plus two pallets can carry the same quantity of resupply as a long module (LM) plus two pallets since the short module fully satisfies the requirements for items which must be stowed internally. The constraint is the loading capability of pallets. Adding more pallets doesn't improve the resupply since, as shown previously in Table 3.4-4, a three segment pallet train carries little more than a two segment train.

Table 3.4-5 Spacelab Resupply: Quantities and Transport Cost

Module	Water (Kg)	Gases (Kg)	Other Consumables (Kg)	% P/L Bay	Transport Cost (M$)	Approx. Man-Day Supply
SM + 1P	810	572	570	65.1	27.05	160
SM + 2P	1350	1045	1140	81.5	31.26	320
LM + 1P	810	572	570	79.8	31.26	160
LM + 2P	1350	1045	1140	96.1	31.71	320
2 Pallets	810	572	570	43.1	12.29	160

The short module plus two pallet configuration is shown in Figure 3.4-3. Standard Spacelab racks would be outfitted with structure for stowing resupply items. These could be sent to NASA or contractor facilities for loading, as is the case with basic Spacelab operations. Perishable (e.g. frozen food) items would be loaded at KSC. Trusses would be built to adapt gas and water tanks to pallets. Such trusses pick up the standard pallet attachment points. Hoses and pumps will be required on the pallets to transfer gases and water to Skylab. The Spacelab could be removed from the cargo bay and attached to the Interface Module. However, this requires a docking adapter, trusswork between pallets and module, and connection with the Interface Module similar to that in the aft Shuttle cabin wall (an additional EVA operation).

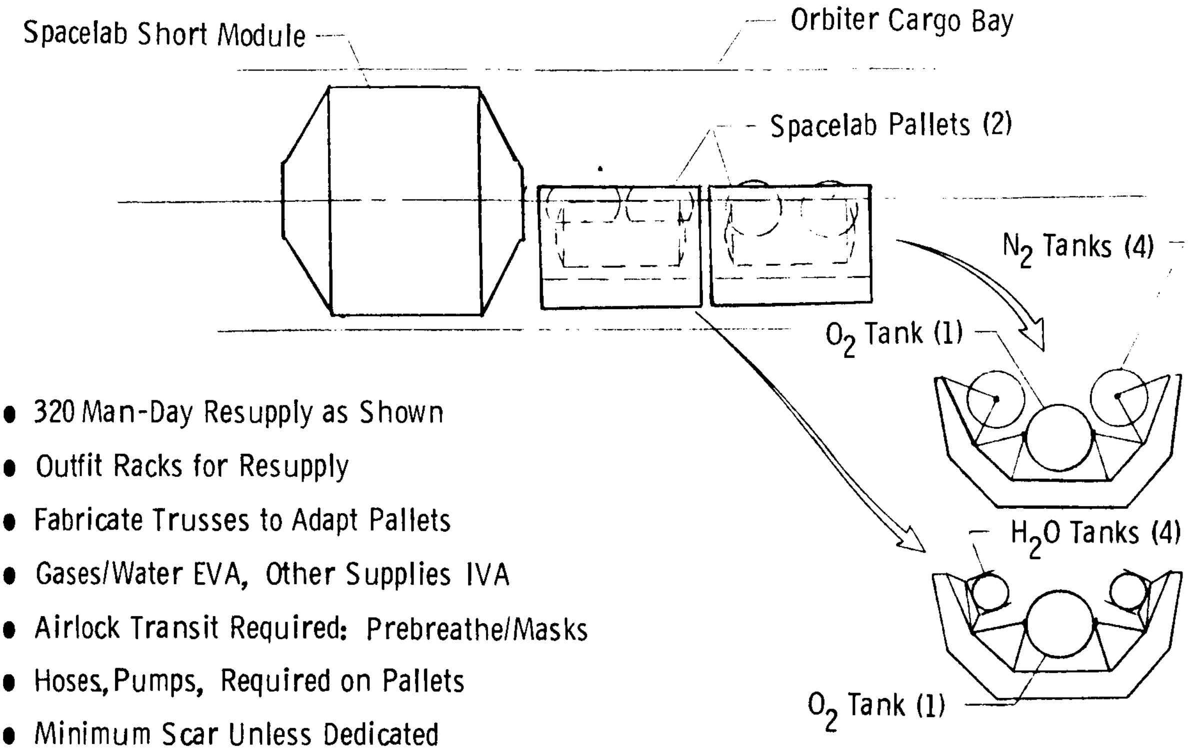


Figure 3.4-3 Spacelab Resupply Option

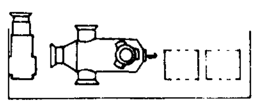
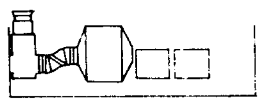
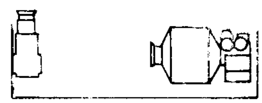
3.4.3 Resupply Comparison

Table 3.4-6 shows a comparison of resupply concepts. The first column uses the Interface Module and two pallets as part of an initial resupply concept of the refurbishment mission(s). Water and gases are mounted on the pallets, and food, hygiene, waste management, and other crew supplies packed inside the module. Internal restraints would be a combination of 1) hard structure, designed for later mounting or stowage of equipment and shelter provisions and 2) straps and nets.

Significant resupply (up to 320 man-days) can be carried during the refurbishment mission(s). The delta cost, using the STS Reimbursement Guide, is relatively low compared with other alternatives.

Comparison of Spacelab to a dedicated Logistics Module shows that use of the Logistics Module is operationally less expensive. Costs to build the module will be quickly recovered in terms of transportation costs. Transportation costs and percentages of the payload bay shown include carrying the Orbiter Docking Module.

Table 3.4-6 Resupply Comparison

Item	I/F Module & Pallets 	Spacelab 	Logistics Module 
Approx Man Days	Tunnel: Adapter: One Piece: From 160 To 320	Up to 320	480 (Config Dependent)
% Available P/L Bay	100%*	81.5	70.7 (53.5% length)
Transport Cost **(M$) (1978 dollars)	Part of Refurb Missions $ 5.21M (Resupply)	$31.265	$22.109
Design/Fab	Add Internal Restraints Build Pallet Trusses Add Hoses/Pumps	Adapt to Racks Build Pallet Trusses Add Hoses/Pumps	New Module
Need Date	1982/83 Pallets 1983 (Option)	1983	1984/85

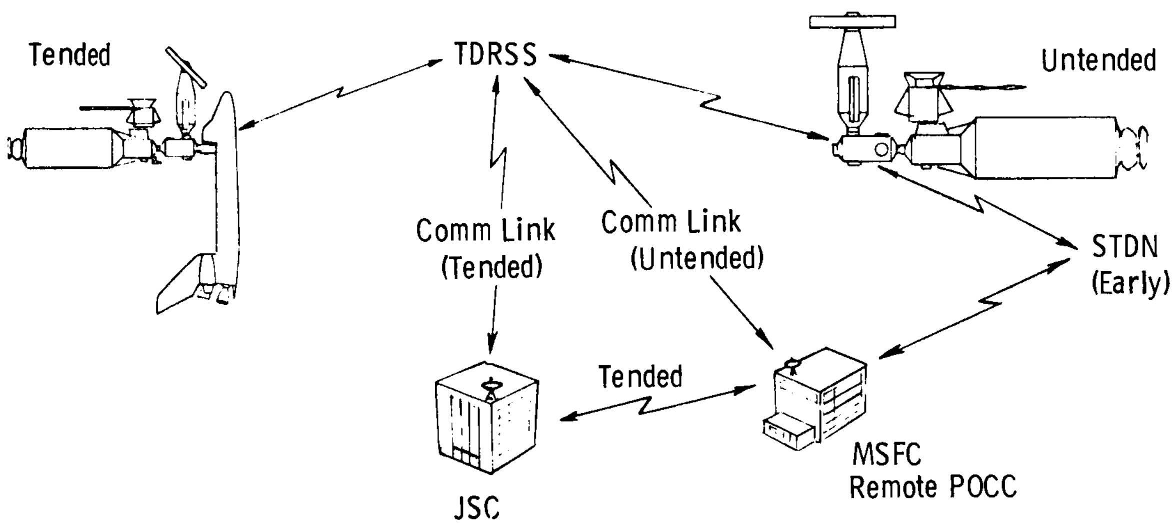
* Total Payload Includes: Orbiter Docking Module, TRS, I/F Module + 2 Pallets (Resupply)

** Reference: Space Transportation System Reimbursement Guide, JSC-11802, Feb. 1978

3.5 OPERATIONS

Several different types of operations are seen for Skylab in a Reuse mode. First, operations are conducted from the Shuttle during refurbishment and early payload missions. Second, after 1984 (probably late 1985), operations are planned untended by the shuttle. At this point, Skylab reuse moves toward long duration, with growth payloads being supplied to the Cluster. This Shuttle can be freed for other shorter duration uses. Untended operations can occur when: 1) Shelter provisions are made available; 2) An antonomous communications system (Ku Band through the TDRSS) is added to the cluster and 3) a logistics resupply system is provided.

A preliminary mission operations concept has been developed to define the elements needed for costing (Figure 3.5-1). During



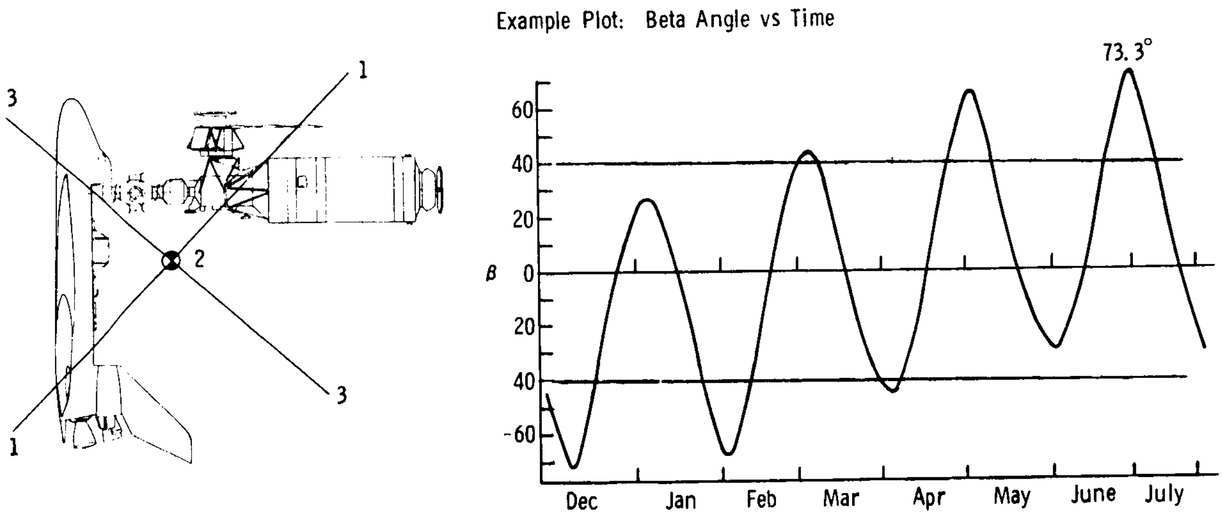
- Shuttle control from JSC
- Limited console positions at JSC POCC (10), not geared to long term operations
  - Long term operations require expansion at JSC or Remote POCC
  - Remote POCC can be at MSFC
- Turnover to other centers / agencies for operations detached from Shuttle presently planned e.g. DOD, GSFC after payload ejection
- Subsystems monitoring: Long term trend analysis and support for emergencies

Figure 3.5-1 Mission Operations Concept the refurbishment flight(s) and those of early Phase III, operations are controlled from JSC. Skylab is essentially dormant for refurbishment missions and crew/shuttle activities are passed through JSC for cluster uplink. Limited console positions are available at the JSC POCC. It is logical to provide data monitoring and analysis at an MSFC POCC with contractor support as required. When untended operations occur, control of Skylab can be transferred entirely to MSFC (these operations are not necessarily continuous). Precedent for this turnover is seen in planning for two agencies. It is planned to have JSC control of Shuttle and payload operations for both DOD and GSFC payloads until released from the Shuttle. Payload operations and control then transfer directly to these agencies.

Refurbishment flights are seen as one-shift operations with the crew working from the Orbiter. The primary ground shift should therefore match the on-orbit shift, with "caretaker" monitoring of crew and subsystems for the rest of the day. Contractor support of NASA is scoped for refurbishment missions as follows: 1) small liaison offices at MSFC, JSC, and KSC (for launch operations only) of 2 to 4 people; 2) approximately 2 specialists/subsystem (15-20 total) during the day shift; and 3) approximately 1 specialist/subsystem during the night shift. Additional analysis support is on-call at the contractors' home facilities. SE&I, refurbishment hardware, and Interface Module teams are adequate to support the short (7-10 day) mission operations. Therefore, we have adopted this approach -- the same concept used on Skylab. Operations costs in Section 5.3 below reflect this concept.

Mission operations during operational flights tended by the shuttle are similar. Shuttle control is assumed to be from JSC, with MSFC as a remote POCC. People from the sustaining engineering teams are located on a temporary basis at JSC and MSFC (and when reuse hardware is launched, at KSC). The sustaining engineering teams can support this concept, based on several missions of about 30-days per year. During continuous operations, a dedicated mission operations team will be required at MSFC.

Launch timing for the refurbishment flights can be selected advantageously (Figure 3.5-2). The Skylab/Shuttle cluster must operate with the number 3 axis shown in the orbit plane. Any inertial orientation can be held within this plane. At Beta angles of $\pm 40^{\circ}$, the solar vector becomes perpendicular to the Skylab arrays. This allows 1) full power from the arrays; 2) operation of the ATM without external Orbiter attitude control; and 3) orientation of the existing parasol perpendicular to the sun. Additional thermal shielding is not needed in this orientation. A Beta angle near $\pm$ 40° will last from one-to-seven-days, depending on which Beta cycle is used. An example set of Beta cycles shows that the February period is about a week, while the January cycle passes quickly through the -40 degree point.



Launch Near Beta Angle of 40°

- ATM Solar Observations/Checkout with Minimum Control Requirements
- Parasol Adequate For Thermal Control
- Solar Array Power 4.9 to 5.5 kW (Beta = 40 $\pm$ 15°)

Figure 3.5-2 Refurbishment Mission Operations Timing

4.0 INTERFACE HARDWARE/DESIGN CONCEPTS

4.1 Interface Module

The primary functions of the Interface Module (IM) are to 1) adapt the Skylab docking system to the proposed Shuttle docking system, provide interfaces for power, fluids, gases, signals, and caution and warning, 2) provide a pressurized interconnecting tunnel between them, 3) provide docking ports for attaching the 25 kW Power Module (PM) and other modules, and 4) act as an airlock both for the interface between Skylab and Orbiter and for EVA operations.

A number of Interface Module concepts were identified for initial study, which considered possible applications of available hardware and design concepts, as well as new designs. The merits of these candidates were evaluated, based on selection criteria including size and weight, redesign needs and potential cost. Two configurations are recommended for detailed analysis 1) a two-piece module featuring an early, relatively inexpensive tunnel section followed later by a docking adapter section and 2) a one-piece module. These are described below.

4.1.1 Requirements

Primary and optional requirements of the Interface Module are outlined in Table 4.1-1, based on NASA inputs and our Skylab reuse analysis. The primary requirements arise from the need for an integrated Interface Module (IM) that performs the multiple docking, crew transfer and shelter functions. The options increase the utility of the IM and could be a starting point for further tradeoff studies of cost effectiveness.

Table 4.1-2 shows the background factors indicating that a Skylab Shelter should be designed for ten-day life support. Input data are based on NASA projections of Shuttle missions in the 1984 to 1990 period. The calculated requirement is to support a wait time of 7.7 days. A 2.3 day (30%) margin is included for contingencies. Detailed requirements for ten-day provisions are described later.

Table 4.1-1 Interface Module Requirements

Primary

- Orbiter Docking Adapter to Skylab
- Shirtsleeve Transfer Between Orbiter And Skylab
- Adequate Clearance
- Facilitate Attachment/Removal of Power Module
- Availability: Early 1982, Baseline
- Launch In Orbiter Bay, Install Using RMS
- Act as Airlock Between Orbiter & Skylab
- Multiple Docking Capability
- Withstand Thrusting and Docking Loads
- Internal Launch Stowage of Refurb Kits To Be Used In Pressurized Areas
- Interface Connectors Among Docking Ports
  - Power, Heat (Fluids), Data, C&W, Communications
- Accommodate Crew Support Systems To Act As Shelter In Untended Mode
- Minimum Internal Diameter = 1 Meter

Options

- Stabilization (Modify Available Skylab CMGs)
- Modules Dock in 14.7 PSI Zone
- Provide Airlock For EVA Operations

Table 4.1-2 Skylab Reuse Emergency Shelter Criteria

Scene:	1984 and beyond -- Skylab operating untended. Emergency requires crew to proceed to a shelter area awaiting rescue.	
No. of Orbiters Flying Out of ETR:	2	
Traffic Model:	15 flights/year each vehicle 10 days normal on-orbit time Both vehicles can be on-orbit	
Rescue Time:	Recall, 7 orbits or less	-- up to 11 hours
	Ground turnaround	-- up to 160 hours
	Launch/rendezvous	-- up to 14 hours
	Maximum Time	185 hours 7.7 days

Anticipate requirements for rescue of Skylab crew by assuring 10 days supply of life-support needs in Skylab/Interface Module shelter areas.

4.1.2 Interface Module - Two-Piece Concept

The two-piece Interface Module (Figure 4.1-1) is aimed at minimizing early year costs. The first piece, a tunnel section, is assumed launched in the orbiter bay in 1982. It provides a means for docking with the Skylab and crew transfer. It also contains refurbishment kits for upgrading and rehabilitating Skylab. Optional capabilities include addition of 1) a 3-CMG package for stability prior to the Power Module and 2) Skylab N_2 and O_2 tanks. We recommend that N_2 tanks be carried on the first flight to partially resupply the TACS. This will allow Skylab stabilization for the next mission without reflying the Teleoperater Retrieval System. The tanks can then be used as the airlock reservoir and the shelter N_2 tank.

The second piece, a docking adapter, is assumed to be launched on a subsequent flight, perhaps with a Spacelab Module plus a pallet equipped with logistics resupply in 1983. It provides docking ports for attaching the 25 kW Power Module to the Skylab complex and for attaching a Logistics Module and Spacelab-derived modules and pallets.

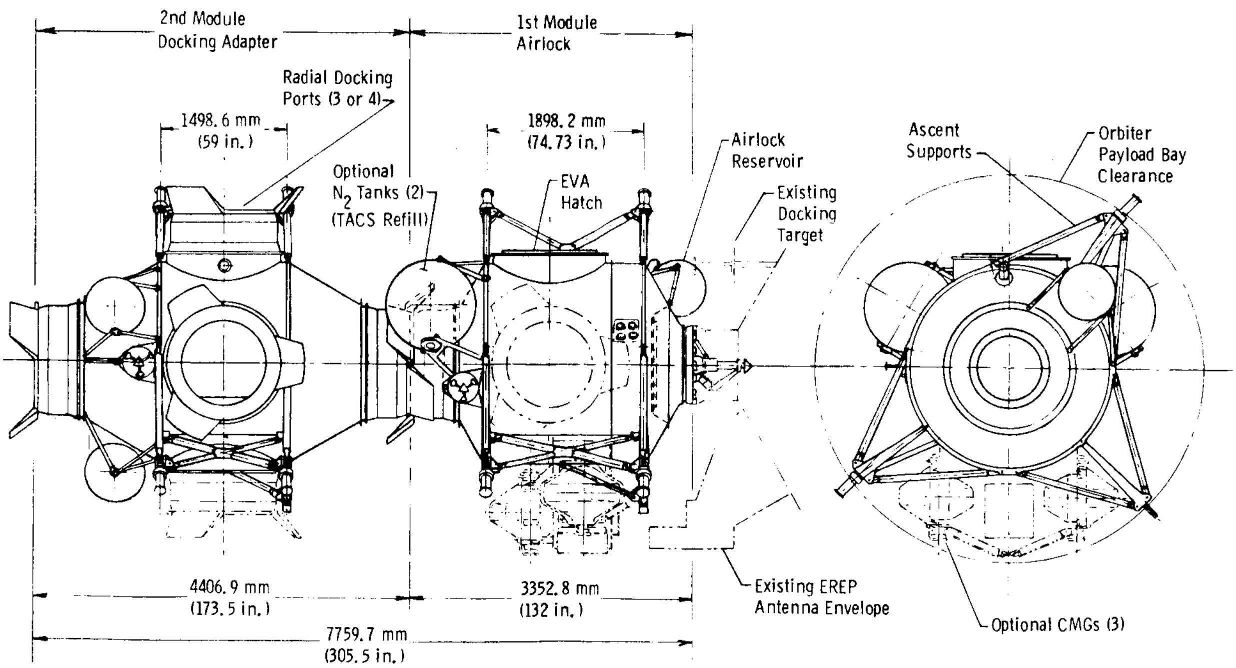


Figure 4.1-1 Interface Module - Two Piece Concept

Some key considerations associated with a 2-piece Interface Module concept can be identified as follows:

- Minimizes early-year funding.
- 1st module provides for Orbiter-to-Skylab docking
  - Includes airlock
  - Accessories can be added later
- 2nd module provides docking for PM and other modules -- can be modified based on results of initial use of 1st module
- Ample volume for stowage of refurb kits
- Can return 1st module and adapt for use in later single-piece module
- Combined module provides shelter for seven crewmen

4.1.3 Interface Module - One-Piece Concept

Figure 4.1-2 shows the one-piece module concept. It meets all design requirements and is focussed towards minimizing total costs. It could be launched in the Orbiter Bay in 1982 or 1983, providing means for Orbiter docking and crew transfer to Skylab, launch stowage of refurbishment kits and multiple docking of payloads and the Logistics Module. Optional components are indicated.

Some key considerations associated with a One-Piece Interface Module are:

- Volume ample for
  - Stowage of refurb kits
  - Shelter for seven crewmen
  - Installation of subsystem components
- Airlock volume is optimized
  - Large enough to contain and transfer resupply items and two crewmen
  - Small pumpdown volume
- Modules can operate at either Orbiter or Skylab pressure
  - Forward modules at Orbiter pressure
  - Aft modules at Skylab pressure
- Higher early-year cost if launched in 1982

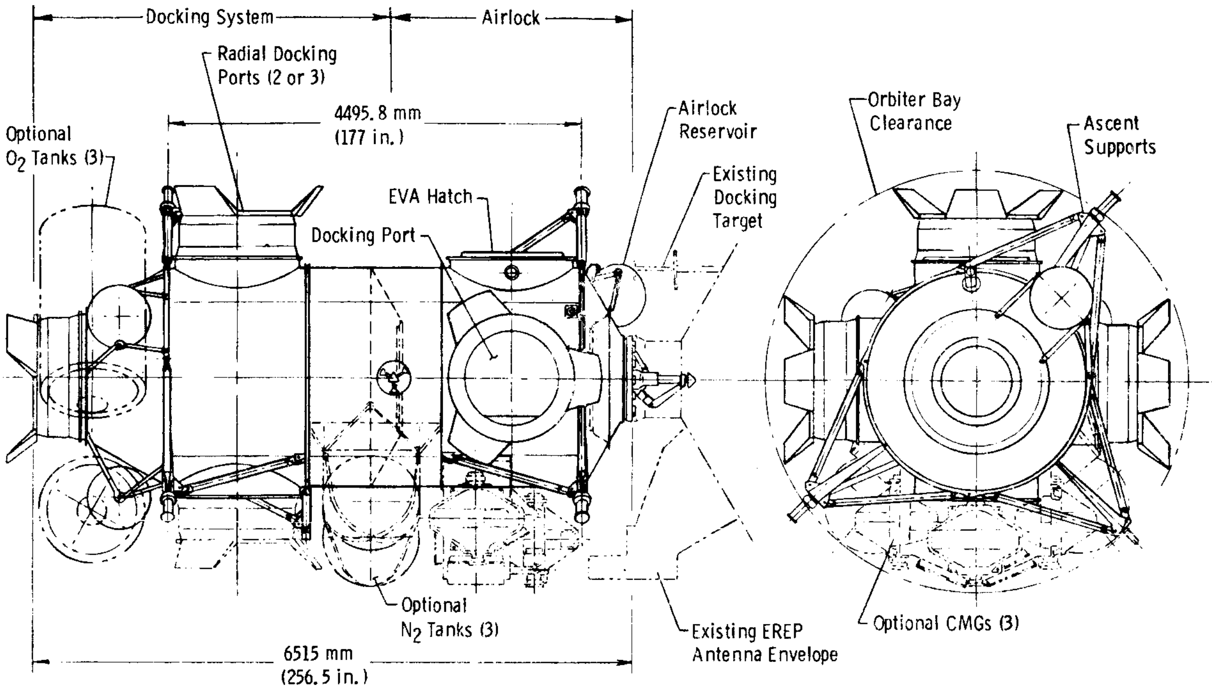


Figure 4.1-2 One Piece Interface Module

4.1.4 Interface Module Equipment - Basic Equipment

Table 4.1-3 identifies basic equipment required for the Interface Module. Part of the air supply and conditioning system is installed prior to its launch, including blowers, ducts, and filters. Other items of the air supply can be installed later, such as, the CO_2 and H_2O removal parts, because these are needed only in Phase IV to fulfill shelter requirements. Similarly, basic S-Band communications are installed initially. In Phase IV a Ku Band system will be added to meet requirements using the TDRSS.

Stowage racks are used to stow refurbishment kits during ascent. At the conclusion of the refurbishment activities, these racks would be 1) removed to free the space they have taken, and would be returned or stowed in Skylab for future on-orbit uses or 2) used to stow shelter supplies and later equipment, such as, the Ku Band system.

Table 4.1-3 Interface Module Equipment List--Basic Equipment

Item	Weight (lbs)	Size (in)	Volume(ft^3)	Remarks
Air supply, conditioning & controls Blowers, ducts, filters, etc.	320		13	
Communications				
Ku-Band System				
Multiplexer	40		0.5	Install In Phase IV
Transmitter	92		1.2	
TDRS antenna	--		--	
S-Band Transponder	24		0.3	
Tape Recorder	106	21 x 17.5 x 6	1.3	
Intercom (SIA) (2)	6	5.2 x 9.5 x 5.5	.3	
Cooling System	89		1.2	
Airlock System				
Pump, lines, controls	37		0.5	
Reservoir	90		--	External
Docking Camera & Mounting	28	7 x 9 x 2.5	0.1	External
TV Input Station	7.4	4.5 x 7.8 x 6.8	0.1	
RMS Fitting	5			External
Cables				
Tunnel	62.5		0.8	
Docking Adapter	100.0		1.3	
Control & Display Panel	30	24 x 12 x 9	1.5	
Electrical Connector Panels (6)	60	12 x 12 x 6	0.5	
Fluid Interface Panels (6)	80	12 x 12 x 6	0.5	
Lights	7		0.7	
Fire Extinguisher (2)	6		0.1	
Stowage Racks (refurb kits)				Remove after refurbishment activities
Tunnel	202		93	
Docking Adapter	100		50	
Caution & Warning System				
Transducers (20T, 8P)	7	--	--	
TOTALS	1196.9		23.9	Excluding racks

4.1.5 Interface Module - Equipment Options

Characteristics of the optional CMG's and supplementary air supply tanks (mounted externally) are shown in Table 4.1-4.

Table 4.1-4 Interface Module Equipment--Options

Item	Weight (lbs)	Size (in)	Volume (ft)	Remarks
Control Moment Gyros (3)	1 236	39 in.sphere	17.97 ea.	External
CMG Electronics Ass'y (3)	24	9.8 x 8.6 x 3.0	0.15 ea.	External
CMG Inverter Assembly (3)	156	25 x 22.5 x 3.5	1.14 ea.	External
O_2 Supplementary Tanks (3)		45D x 90	82.8 ea.	External
O_2	2 808			
Tanks, supports, plumbing	8 845			
N_2 Supplementary Tanks (3)		41D	20.7 ea.	External
N_2	754			
Tanks, supports, plumbing	1 263			
TOTALS	15 086			All External

4.1.6 Shelter And Rescue

1) Skylab Approach

Before addressing shelter and rescue considerations for the Skylab complex of the 1980's, it is worthwhile to review the approach used previously on the Skylab program during 1973 and 1974. The considerations and plans for rescue contingencies were based on possible failures preventing access to the CSM or return in the CSM. Skylab was considered a habitable, redundantly safe system providing ample safety and life support for a crew awaiting rescue.

The CSM that launched the crew remained attached to Skylab until it was time for the crew to return. If this CSM became disabled, a second CSM would be launched with two-crew on board to participate in the rescue. This CSM was to be modified during part of the rescue countdown sequence to accommodate the additional three-crew on Skylab during the return. The wait time for rescue could be as long as 46-days depending on the status of the second CSM and of the assigned Skylab launch pad at ETR.

During the waiting period, the crew would use Skylab as a shelter, conserving power and air supplies, as the situation required. Of course, in the event the Skylab became disabled, the crew would go into their attached CSM, separate from Skylab, and return to earth. If this CSM were incapable of crew return, it would be jettisoned to permit the CSM rescue vehicle (RV) to dock on the axial MDA port. If jettison were impossible, the RV could dock to the side port. Twelve-hours before the rescue rendezvous, the crew would close down the OWS and wait in the MDA/AM area.

The MDA and AM of Skylab have large volumes and contain much life support equipment, including controls and displays. Table 4.1-5 lists items in the MDA/AM pertinent to contingency usage (but also used during normal operations). These volumes of Skylab are a safe environment for awaiting rescue.

Table 4.1-5 Shelter and Rescue--MDA/AM Accommodations

MDA	
Free Volume - 400 ft^3	Window
Two Docking Ports	Fire Extinguisher
AM	
Free Volume - 300 ft^3	
EVA Airlock, Hatch & Support	S-Band Communications
EVA Umbilical Provisions	VHF Communications (Voice and Data)
Main Power Distribution & Control	UHF Ground Command Receivers
Atmospheric Supply, Conditioning & Control	VHF Ranging Link
Thermal Control	Teleprinter
STS & Tunnel Sections	
Molecular Sieves	OWS Cooling
O_2/N_2 Control	Stowage Containers
Cabin Heat Exchange	
ATM & LCG Water Tanks	

The crew can isolate themselves from the OWS if necessary, because the breathing atmosphere fill and circulation system to the OWS can be shut-down. Figure 4.1-3 illustrates the Skylab air supply systems. The fill valve normally would be closed after the OWS air pressure has been stabilized. As the crew leaves the OWS, the pull-thru flex duct is disconnected at the

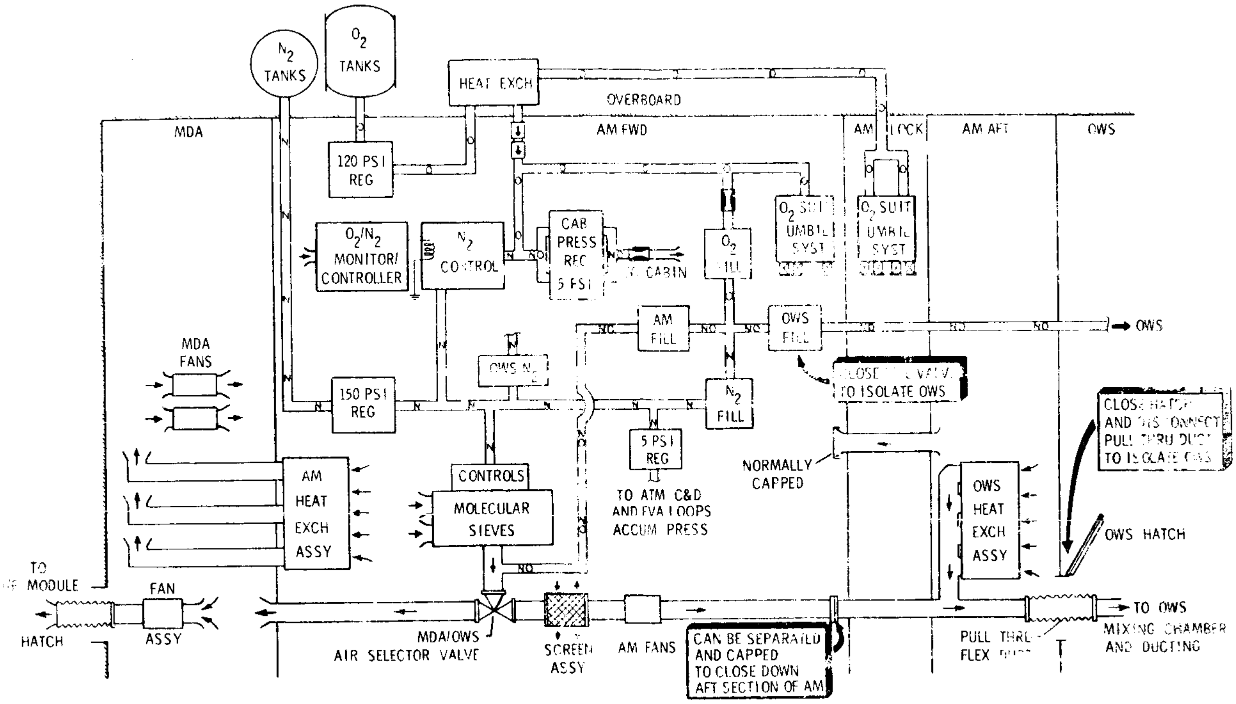


Figure 4.1-3 Fill and Circulation System--OWS Isolation

OWS hatch, pulled into the AM aft section, and the hatch is closed. If the AM aft section is also to be isolated, it is necessary to disconnect the air circulation duct and put a cover on it at the place shown in the schematic chart. All these activities can be performed in a short time span,(several minutes) assuring a safe shelter in the MDA/AM.

Skylab Caution and Warning (C&W) System provided crew alerts for caution, warning, and emergency contingencies. There were numerous caution items that required notice and response by the crew, but were not an imminent threat to safety. On the other hand, the Skylab warning and emergency items that required action were as follows:

Warning Items	Emergency Items
AM: PPO_2	AM: Fire
	$\Delta P / \Delta T$
Coolant Pumps	
Reg Bus High/Low	MDA/STS: Fire
EVA LCG Pump ΔP	OWS: Fwd Fire
EVA H_2O in Temp.	Aft Fire
Crew Alert	Crew Quarters

Basically, the warning items included abnormal deviations in partial pressure of oxygen, coolant pump operations, Bus voltage and EVA pump pressure, and water inlet temperature. The emergency items were to indicate fire or large pressure change. Sensors, warning lights, and klaxons have been located in various areas throughout Skylab.

2) <u>Shelter Requirements and Systems</u>

Specific requirements for an area to be used for shelter include space, food, water, air and air processing, pressure suits, controls and displays, and other life-support aids (Table 4.1-6). Requirements are derived from Skylab experience and from data on consumables used during previous Skylab missions which meet or exceed minimum medical and safety criteria.

Table 4.1-6 Shelter Requirements

Crew Size	Up to 7
Duration	Up to 10 days
Free Volume	At least 50 ft^3/man; also allow for 2 crew to don/doff pressure suits; provide Airlock for EVA
Food	1 to 1.5 lb/man day (high density, high protein, dry food bars, no rehydration requirement)
Water	4 to 5 lb/man day
Air: Oxygen Nitrogen	2.08 lb/man day 0.08 lb/man day } includes allowance for leakage
CO_2 Removal	2.2 lb/man day (also remove trace contaminants and odors)
H_2O Removal	0.73 lb/man day (include humidity and temperature controls)
Pressure Suits	Two required (EMUs, 5 ft^3 each stowed)
C & D Panel	C&W displays, atmosphere and communications controls
Sleeping Aids	Minimal; body restraint straps, isolation head hoods
Cleanliness Aids	Sanitary wipes
Waste Management	Fecal and urine bags; dispose of waste and other debris in sealable trash bags
Safety Aids	Lighting, first aid/medical kit, fire extinguisher, communication to ground and rescue Orbiter

Characteristics of shelter systems meeting specific life-support requirements for ten-days wait time are tabulated in Table 4.1-7. These are additions to the basic systems needed for normal operation of the Skylab Complex. Air tanks would be mounted outside (external) of the shelter area because of their large volume and high pressure. The CO_2 removal system is based on use of LiOH, since this is the lightest system within the 70 man-day requirement.

Table 4.1-7 Shelter Systems to Meet Requirements

Item	Weight (lb)	Volume (ft^3)	Remarks
Food	100	2	14 lbs/man
Water	330		47 lbs/man
Tanks (2 STS)	141	11	
Air	208		30 lbs/man, including leakage. Includes supports, plumbing
Tanks	435	19 (External)	
Ducts, Fans, etc.	320	13	
CO_2 Removal	545	10	LiOH, 35 canisters
H_2O Removal	70	2	
Pressure Suits (2)	406	10	EMUs, Shuttle programs
Disposal Bags, Wipes, Sleeping Aids, Medical Kit	123	4	
Communications			Included in "Basic"
C&D Panel			Included in "Basic"
TOTALS	2676	52 (19)	Internal (External)

3) Skylab Complex Shelter Accommodations

In this section various alternatives for shelter and rescue in the Skylab-reuse complex are described. The numerous EVA hatches, internal hatches, docking ports, and airlocks are shown in Figure 4.1-4. These provide isolation of sections of the complex, transfer of crew to the Orbiter and, as backups, transfer through EVA hatches to an unattached rescue Orbiter. There are a number of shelter areas available to accommodate all resonable contingencies.

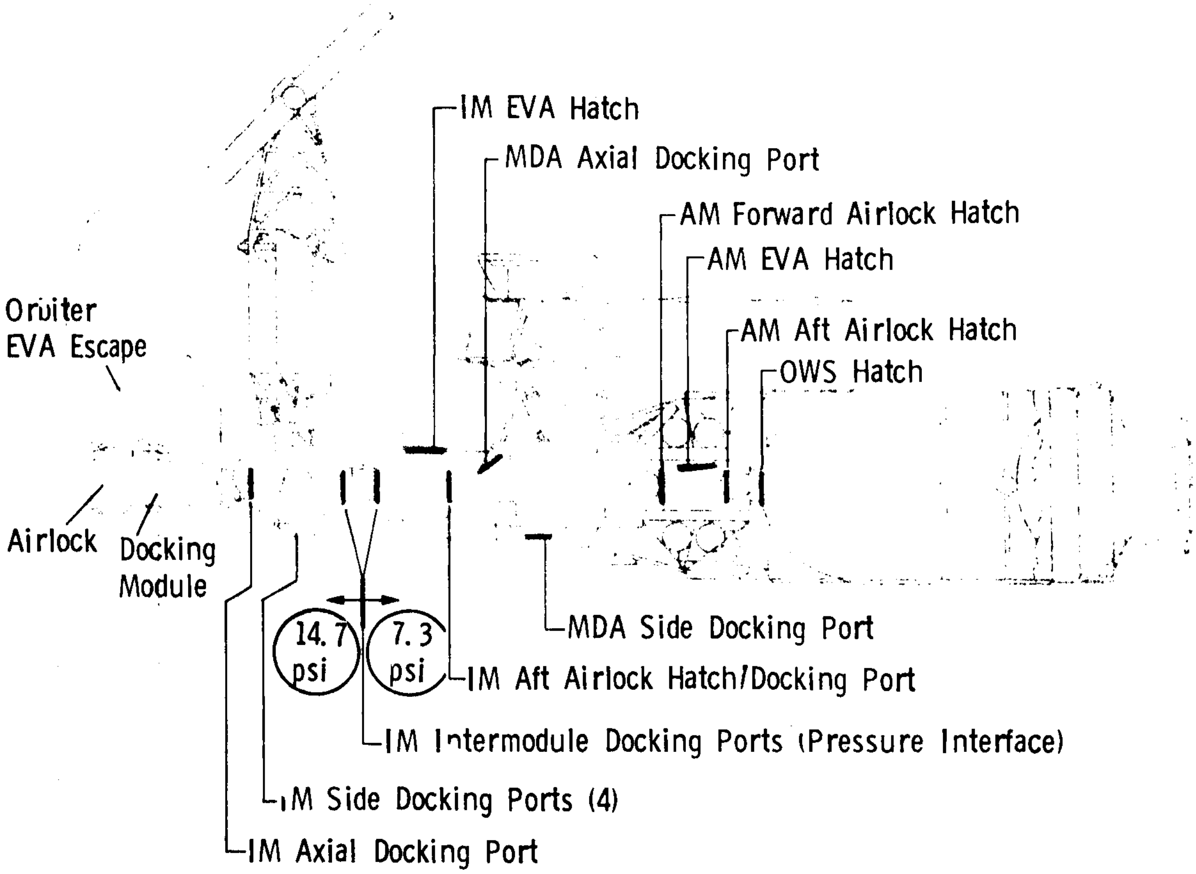


Figure 4.1-4 Skylab--Complex Hatches

The primary areas are 1) the basic MDA/AM/OWS 2) the MDA/AM plus the Interface Module (and Logistics Module). First, consider a failure which requires shelter in the MDA/AM/OWS. This is an obvious shelter alternative, as it was considered for this contingency in the previous Skylab program. As depicted in Figure 4.1-5, life support provisions are available, including stowage of two EMUs in the OWS for EVA/IVA to perform diagnostics or corrective action, or to assist in the rescue/rendezvous operations. Two additional EMUs are stowed in the Interface Module and could also be accessible from the Skylab shelter. The crew can transfer to the rescue vehicle through the Interface Module, or as a backup, via EVA from the Airlock Module or the airlocks.

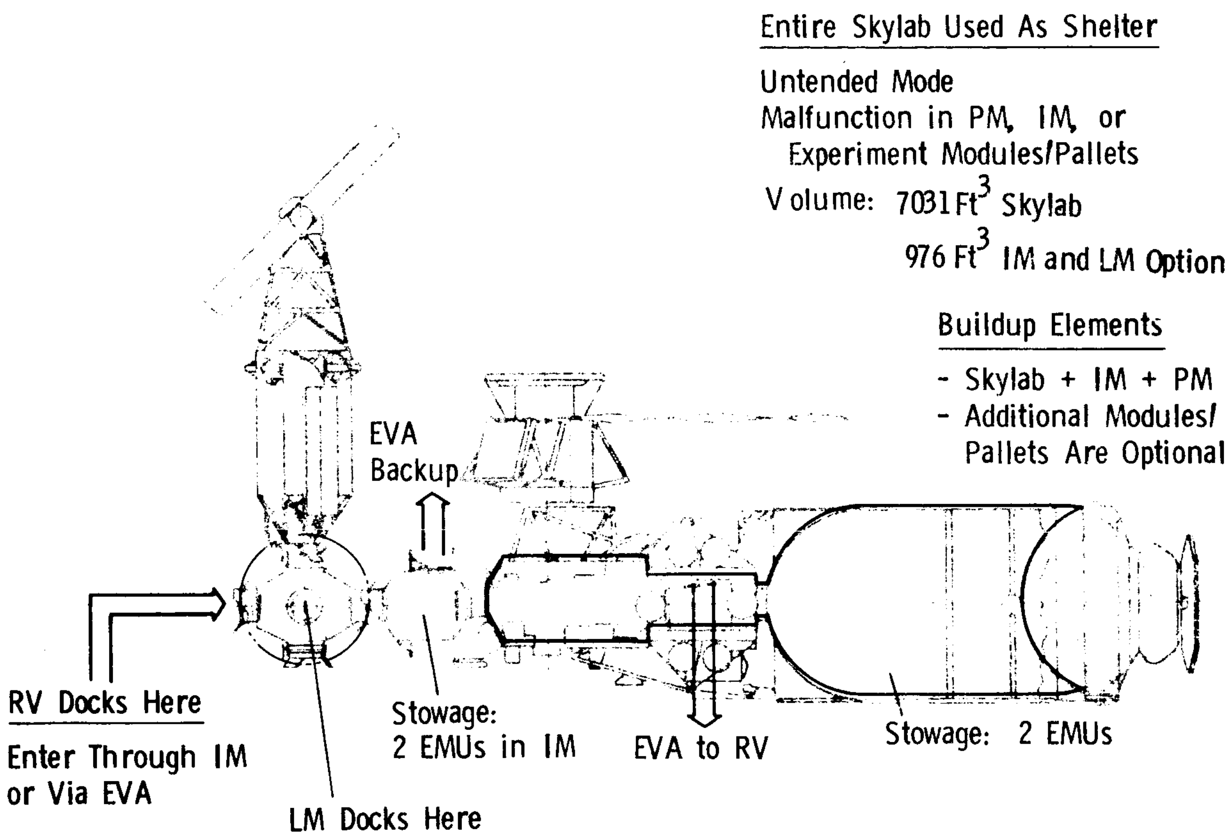


Figure 4.1-5 Shelter Alternative 1 Concept

If the contingency requires the OWS to be shut-down, the MDA/AM and Interface Module can be used for shelter (Figure 4.1-6). The OWS hatch and air supply can be closed. The Logistics Module is attached to the Skylab complex and is a source of food, water, and other contingency consummables. The two EMUs installed in the Interface Modules meet EVA/IVA shelter requirements. The rescue vehicle, however, can dock at the axial port and receive the Skylab crew as normal. This alternative shelter concept utilizes the basic MDA/AM habitation accommodations that include C&DH, ECS, and associated controls and displays. Although the OWS sleeping areas, waste management, and other accommodations are not available, the temporary needs of the crew are amply provided by the MDA/AM and Interface Module facilities.

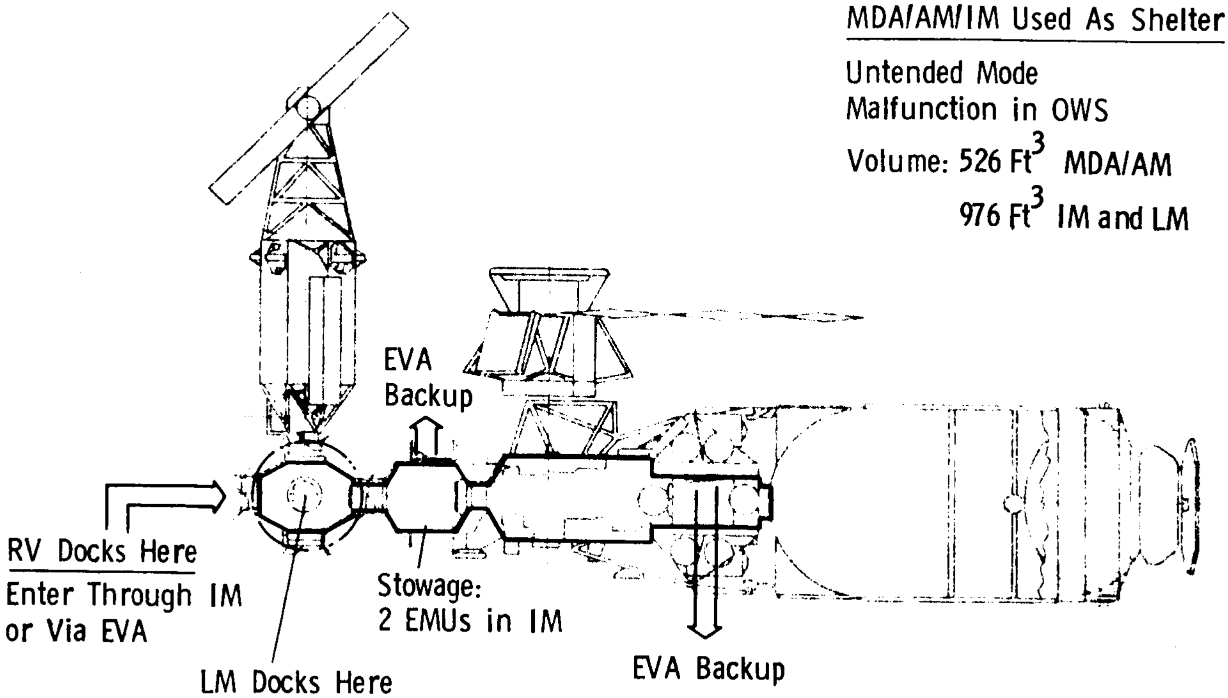


Figure 4.1-6 Shelter Alternative 2 Concept

If the contingency requires that MDA/AM be shut down, the Interface Module together with the Logistics Module must provide shelter accomodations (Figure 4.1-7). Our guidelines for the Interface Module design as a shelter assure that it has at least the minimum life support provisions for 70 man-days, drawing on the Logistics Module for food, water, and other consumables as well as a supplementary sleep area. The rescue vehicle can dock and crew transfer can take place as normal. With this shelter alternative, the systems can be shut down to the lowest levels of power air usage during the wait time because of the small shelter volume. But, because the Skylab facilities are not accessible, the Interface Module must provide the temporary needs of the crew. These requirements include uplink/downlink communications; control display station; ECS independent air system; items necessary for temporary eating, sleeping and waste; and stowage of EVA suits (two EMUs).

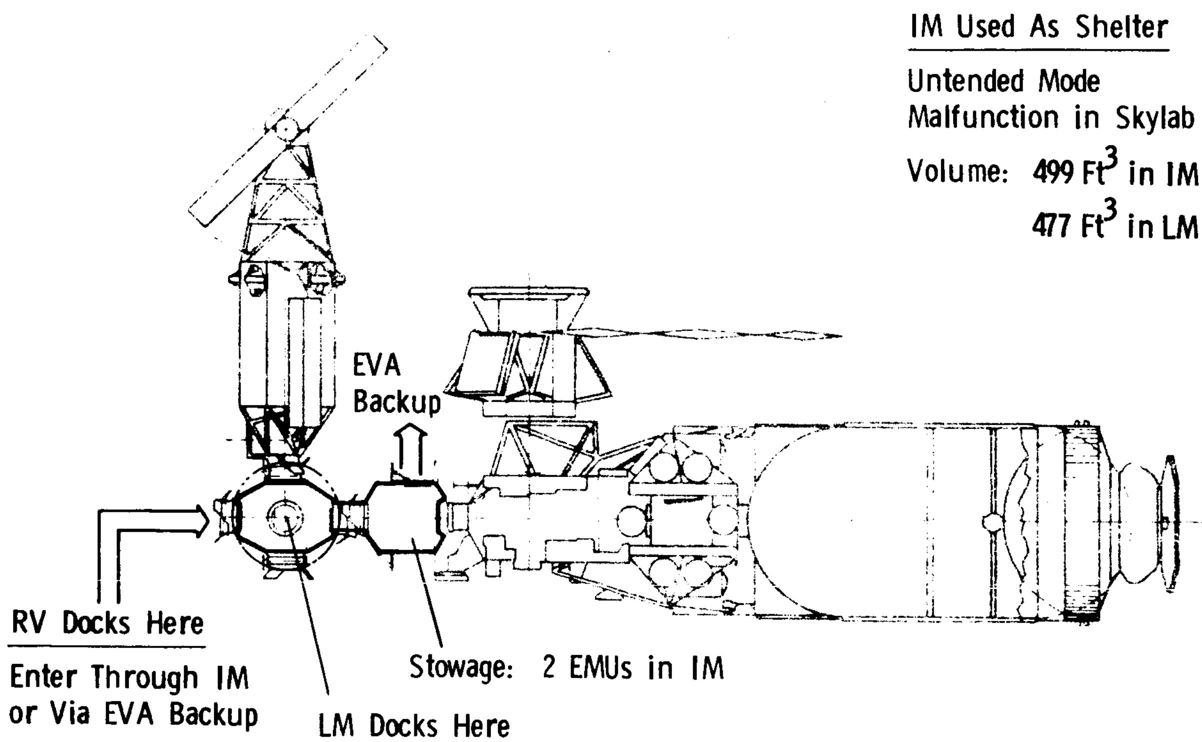


Figure 4.1-7 Shelter Alternative 3 Concept

4) Interface Module Accommodations For Use As Shelter

Shelter accommodations can be designed as parts of either a one-piece or two-piece interface module. Our analysis indicates the feasibility of placing these accommodations in locations shown in Figure 4.1-8. Details of the mass properties, sizes and locations of the components remain to be determined. Free volumes of the two Interface Modules are nearly the same and exceed the minimum shelter requirement of 50 ft^3/man by 42%. The two major compartments of the two-piece Interface Modules, however, are somewhat smaller than the two compartments of the one-piece Interface Module. In summary, the free-volumes provided by various shelter areas are as follows:

	Volume (ft^3)	
MDA/AM	400/300	100 ft^3/man
Two-Piece Interface Module	230/239 + 30	71 ft^3/man
One-Piece Interface Module	508	72 ft^3/man
Logistics Module	477	68 ft^3/man

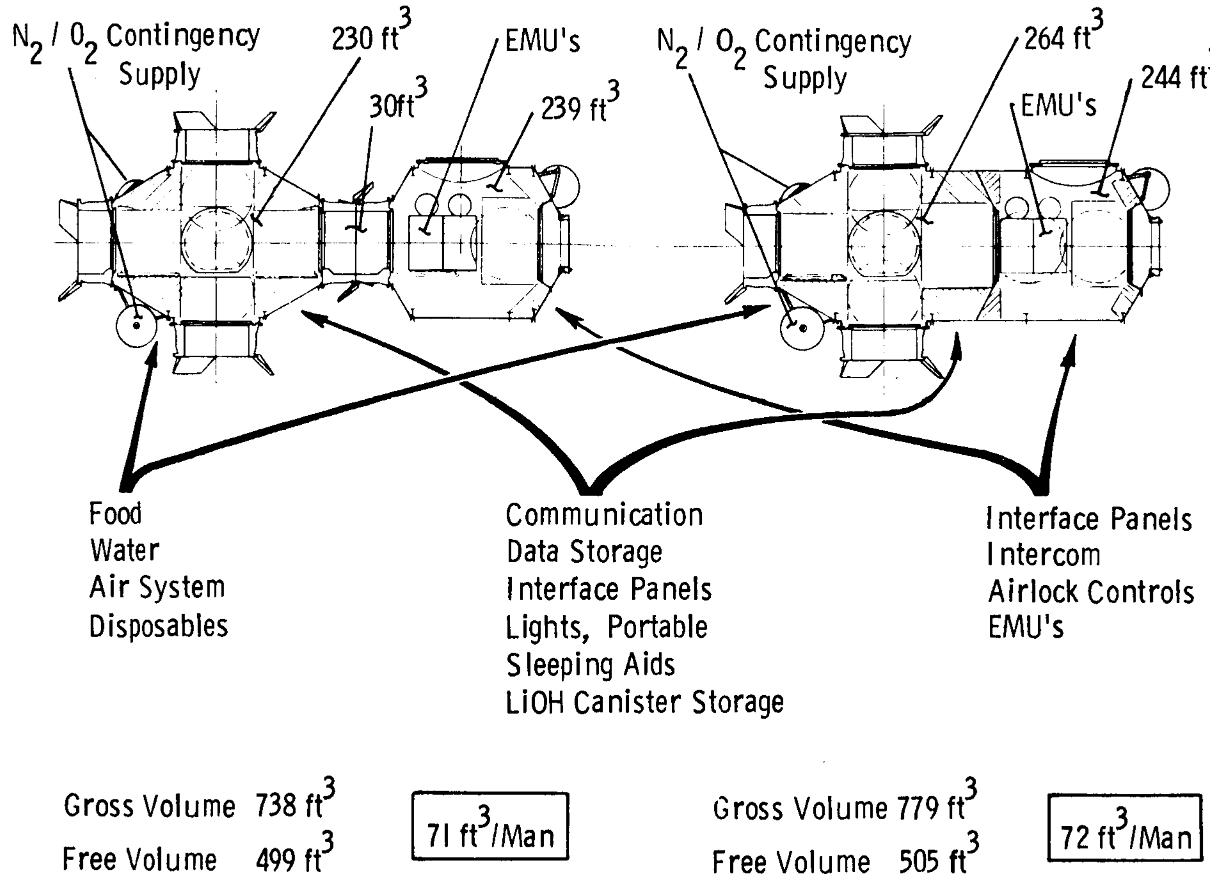
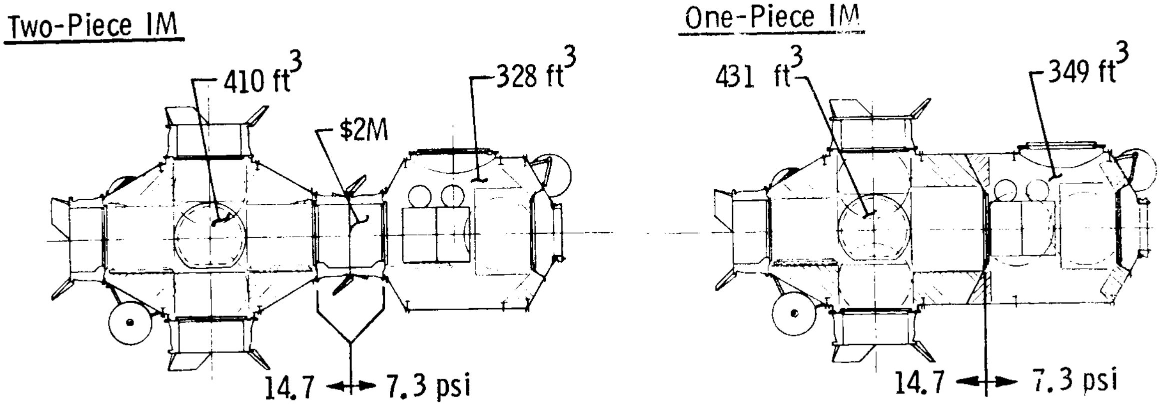


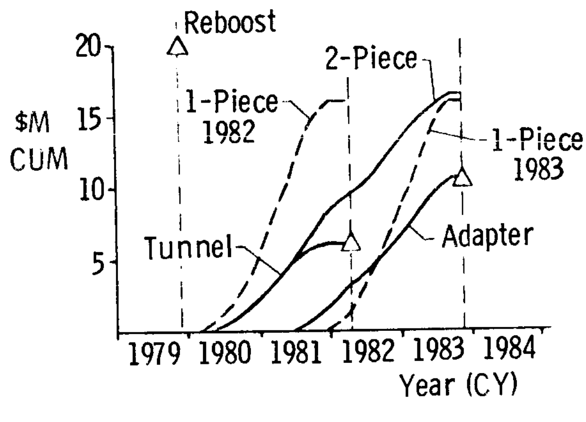
Figure 4.1-8 Interface Module Accommodations for Use as Shelter

4.1.7 Interface Module Comparisons

Features of the two-piece and one-piece Interface Modules are summarized in Figure 4.1-9,which illustrates comparative physical characteristics and cost projections.

Gross volumes of the corresponding two sections of the one-piece module are 5% larger than those of the two-piece module (excluding the central docking adapter). Together with more uniform cylindrical geometry, this implies somewhat more ease of integration and efficient internal arrangement potentials for the one-piece module. It has an advantage in transportation to orbit costs as it requires only one Shuttle launch and rendezvous with Skylab. The two-piece module has an advantage in flexibility. For example the second piece can be modified





Comparative Advantages

	1-piece	2-piece
Early cost	√ if late 83	√
Total cost	√	√
Shelter	√	√
Resupply	√ if late 83	√
Flexibility		√
Transport Cost	√	

Figure 4.1-9 Interface Module Comparisons

before its launch,if required by findings of the first refurbishment mission. With the data available, there is no overriding advantage of either concept.

Hardware cost projections are approximately the same for both modules ($16.1 million for the one-piece and $16.5 million for the two-piece module, respectively). Schedules and costs including the guidelines and bases of the estimates, are presented in detail in Section 5.0. The present chart shows that the two-piece module is assumed to have a longer time span for design, development and test (first piece launched in 1982, second in 1983). Cumulative costs during the first two years (1980-81) are lower than for the one-piece IM over its 30-month total span (launched in 1982). The equipment includes:

Stowage Racks
Cables
Instrumentation
Intercom Stations
TV Input Station
Electrical Connector Panels
Fluid Interface Panels
Air Blower and Ducts
Fire Detector System
Fluid Control Panel
Docking Camera
Pump Down System (For EVA Operations)
TACS TRUSS and Communications

4.1.8 Alternate Configurations

The one and two-piece Interface Modules (IM) described earlier were designed for minimum cost and minimum requirements. They compromise buildup potential of the Skylab space platform complex, as only two docking ports are available for Spacelab type module or pallet docking. One of these ports will most likely be dedicated to the resupply module. A slight lengthening of the interface modules (30" for the two-piece IM and 60" for the one-piece IM) opens the possibility of adding two more useable ports for docking experiment modules. This can provide a cost effective capability since payloads/modules can be stored on the cluster, avoiding frequent transportation to and from orbit. Skylab then becomes a national payload facility with habitability for either periodic or continuous manned operations.

1) Two-Piece Interface Module

At least a five-meter distance is required between side docking ports to allow Spacelab-size payloads to be docked alongside each other. This requirement is accommodated by lengthening the Interface Module Tunnel section by 30-inches (Figure 4.1-10). The ports on the adapter section, the 14.7 psi-pressure area, would receive the Power Module and Spacelab derived experiment modules (and pallets). The side port in the tunnel section which is the lower pressure airlock compartment, would receive the Logistics Module. A port on the opposite side can be provided for experiment pallets or modules operated at the lower pressure.

The EVA port is located in the tunnel/orbiter section. If, at a later date, it proves desirable to isolate EVA activity from normal passage airlock activity, a Shuttle Airlock Module can be attached to this port (with an appropriate adapter ring).

This concept fulfills all interface requirements, including shelter. It offers operational flexibility, especially for evolution into the untended mode, i.e., the design of the adapter section of the IM is directly applicable to form modal points, if extensive platform build-up at a future date is desired. Optional CMG-packs can be attached.

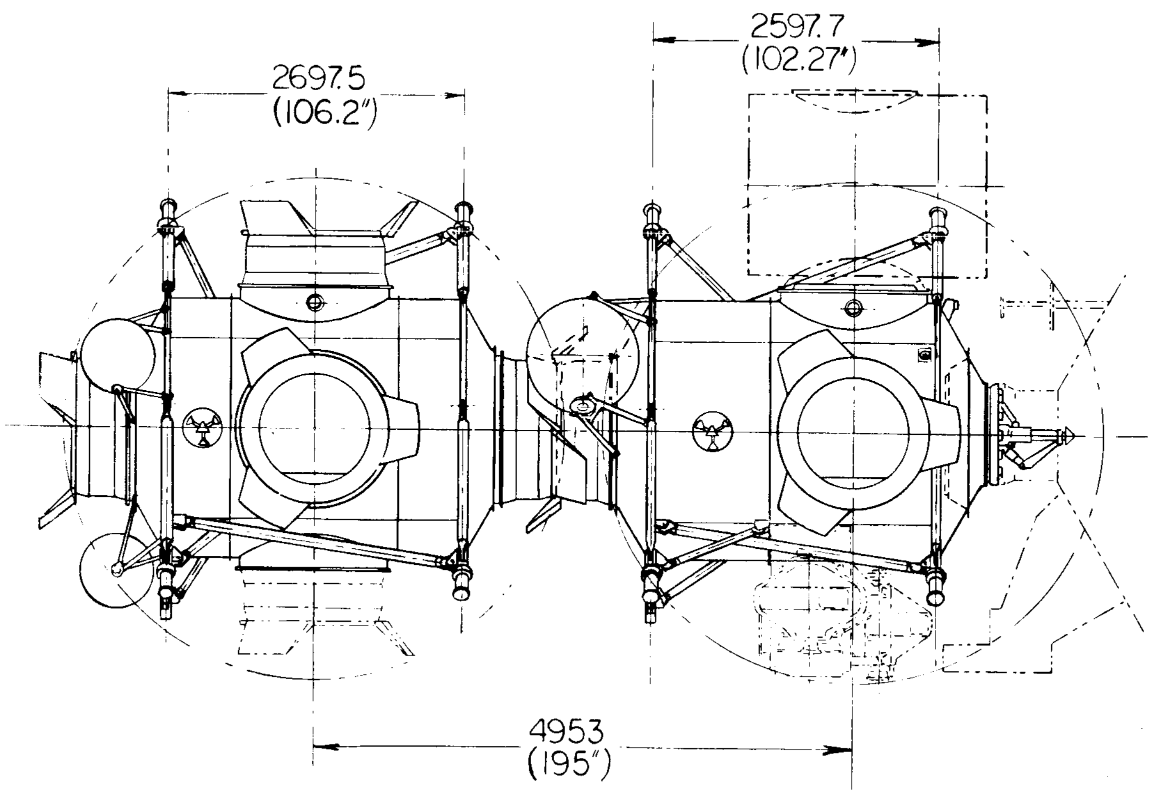


Figure 4.1-10 Interface Module Alternate Two Piece Configuration

2) One-Piece Interface Module

An alternative for a one-piece Interface Module is designed to create two distinct pressure compartments, one always operating at the shuttle pressure level, the other operating at Skylab pressure with the airlock located in between. Furthermore, it has at least a five-meter distance between side docking ports to allow Spacelab-size payloads to be docked alongside each other. Both of these requirements are compatible and result in the alternate design (Figure 4.1-11).

The high-pressure side docking ports receive Spacelab derived experiment modules (and pallets) and the low pressure side docking port accommodate the Logistics Module. Another port can be provided for experiment pallets or modules operated at the lower pressure.

The EVA port is located in the airlock section. As mentioned before, this port can also receive the Shuttle Airlock Module, if desired, to isolate EVA activities. All interface requirements including shelter provisions can be fulfilled. Optional CMG packs can be attached.

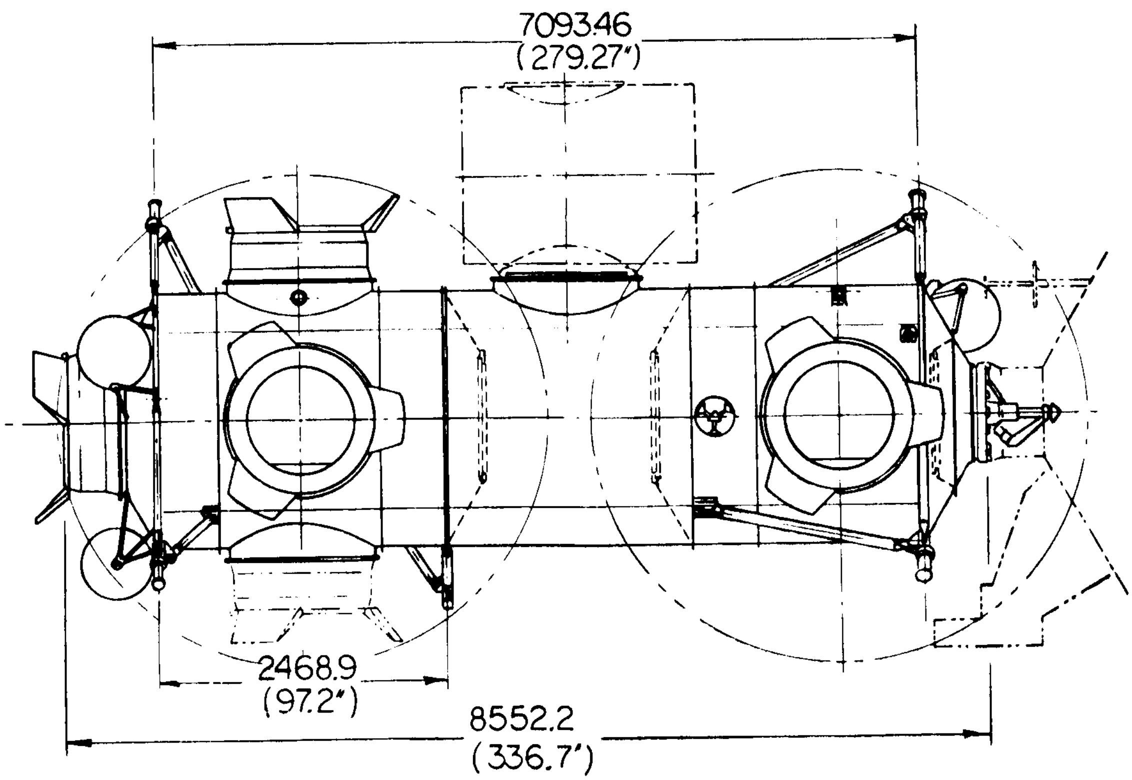


Figure 4.1-11 Interface Module: Alternate One-Piece Configuration

4.2 POWER MODULE

4.2.1 Power Module Baseline Design

The main purpose of the 25 kw power module baseline vehicle is to provide electrical power to other vehicles. In addition, the power module can provide heat rejection capability using four orbiter-type radiators.

Autonomous control is maintained with three CMGs under direction of a NSSC-II computer. With exception of the computer, the control subsystem hardware (three CMGs, two sun sensors, nine rate gyros) is Skylab backup equipment However, the CMGs are being modified, with the major impact being the removal of gimbal stops which simplifies the CMG control law.

S-Band communication capability is provided to communicate directly to ground or to go through the TDRSS satellites.

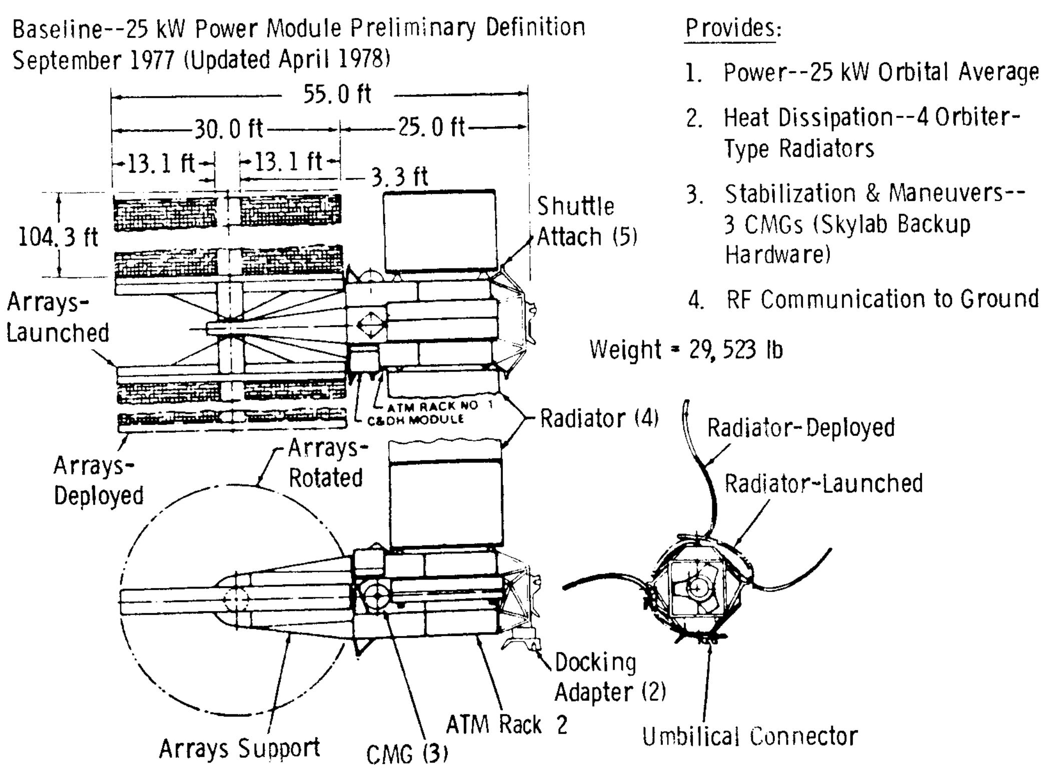


Figure 4.2-1 Power Module Baseline Design

4.2.2 Impact of Skylab Reuse on Power Module

The baseline power module requires few modifications to operate with the Skylab/Shuttle cluster. Operation of the cluster requires the equivalent of five CMGs plus a spare. Three CMGs must be added, either to the Power Module or the Interface Module. Software for cluster control will also be required. Furthermore, two Power Module radiators must be relocated to clear the ATM.

For Skylab applications, the side docking adapter of the baseline Power Module is unnecessary and can be eliminated as it is designed for docking to the Shuttle only.

For Phase IV operation, the Skylab complex requires a Ku Band communications system, including a steerable high gain antenna for communication to the TDRSS. It is a simpler operation to add this antenna to the Power Module on the forward end of the array support structure (antenna mast folded once for transportation) rather than to install the antenna by means of EVA on any other part of the complex (ATM trusses). However, our baseline adds the antenna to Skylab structure. This allows removal of the Power Module for other uses or maintenance while retaining communications with the TDRSS ground station.

5.0 PROGRAMMATICS

Programmatic data (Work Breakdown Structure, Schedules, and Costs) are presented in this section. These data are based on the hardware and software definitions and the basic schedule milestones defined in earlier sections of this report. Data are presented for a baseline case and a number of options. The baseline consists of two refurbishment missions, one in early 1982, one in late 1983. In the first mission, a simple tunnel section is provided to interface between the Orbiter and Skylab. Refurbishment kits are installed and the Thruster Attitude Control System (TACS) resupplied. In the second mission, a multiple docking adapter section is added, providing docking/berthing ports for the power module and payload modules/pallets. Additional kits, including those defined as a result of the first mission, are added at this time and, as an option, initial resupply occurs. The baseline case and options costed are as follows:

1) Two Piece Interface Module Program: No resupply;

2) Add resupply to item 1;

3) One Piece Interface Module Program in 1982: No resupply;

4) One Piece Interface Module Program in 1983: With resupply

5.1 SCHEDULES

Using schedule ground rules from Section 1.0 and technical data from Sections 2.0 through 4.0, schedules were prepared for Skylab reuse. These schedules show the need dates and time spans used in spreading costs in Section 5.3 below. They also show need dates for other program items required to support reuse such as mission control and the Shuttle docking module.

Figure 5-1 shows the baseline schedule for the two-piece interface module case. The reuse study is shown continuing until the time that Skylab is reboosted by the Teleoperator Retrieval System (TRS). The decision to proceed with the tunnel section of the interface module is assumed to be made soon after reboost in late 1979. Preliminary plans and specifications should be well developed at that point so interface agreements (ICDs and specifications) can be reached among Orbiter, Power Module, and reuse participants. Commitment for CMGs and other I/F module components is needed in early 1980 so that installation can occur in mid-1981. A neutral buoyancy article will be delivered to NASA in late 1980 for evaluation of reuse EVA operations. Results of these tests will be fed back to design. Refurbishment kits will be needed at the end of 1981 for integration and crew training. Mission control and the Shuttle docking tunnel are also needed in late 1981 to support preparations for the first refurbishment mission in early 1982.

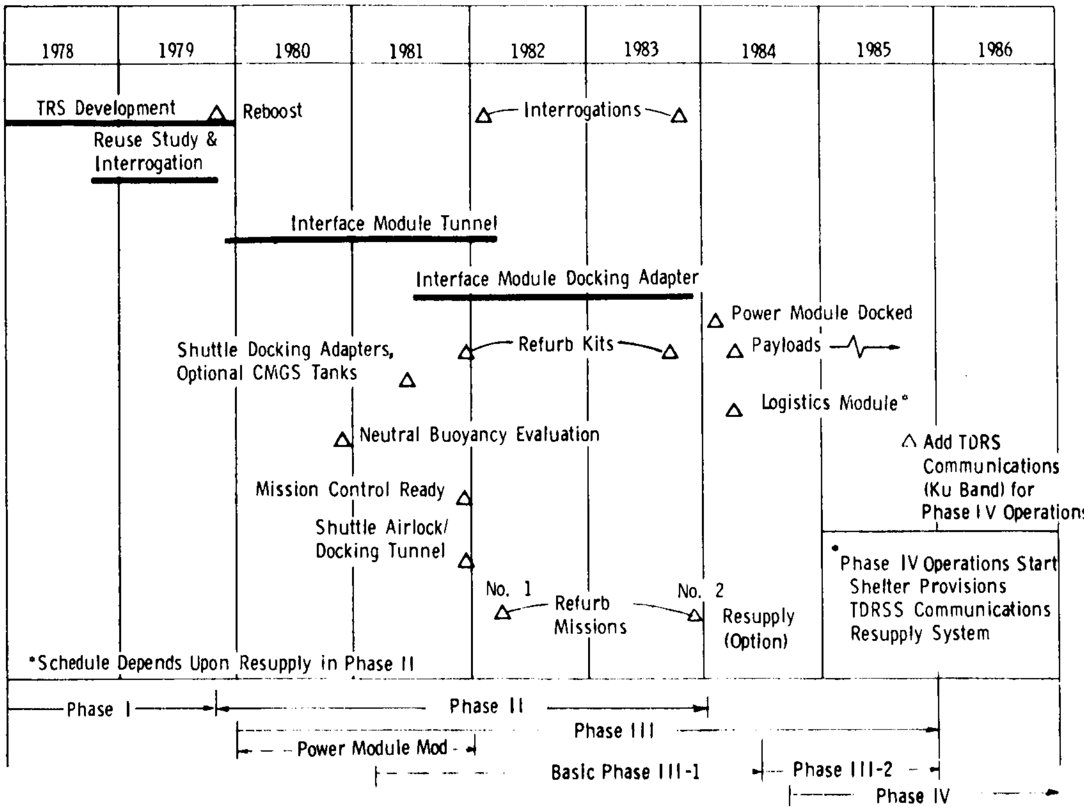


Figure 5-1 Baseline Reuse Program Schedule - (Two-Piece Interface Module)

Some work must be started on the Interface Module Docking Adapter before the first refurbishment mission. However, the bulk of the funding need not be committed until after the first mission. Time lines and payload weight statements show that significant initial resupply can be provided during the second mission. If this option is selected, nonperishable items will be needed for integration and training several months prior to flight.

The Power Module is shown docked in January, 1984 as defined in study ground rules. Payloads should be planned shortly thereafter. The need date for the logistics resupply module depends on the amount of initial resupply provided during mission no. 2 and the program buildup rate in 1984. As stated in Section 3, approximately 320 man-days can be delivered in the initial resupply on refurbishment mission No. 2, allowing three 30-day missions prior to the next resupply.

Phase IV, defined as operations untended by the Shuttle, can begin when prerequisites shown in the figure are provided. For costing purposes, however, untended operations are assumed at the end of 1985. At this time 1) provisions are installed on board to allow crew shelter in the event of basic subsystem malfunction, 2) Ku band communications are installed on the cluster, and 3) a resupply system is available.

The baseline schedule is detailed in Figure 5-2 for Phase II. In

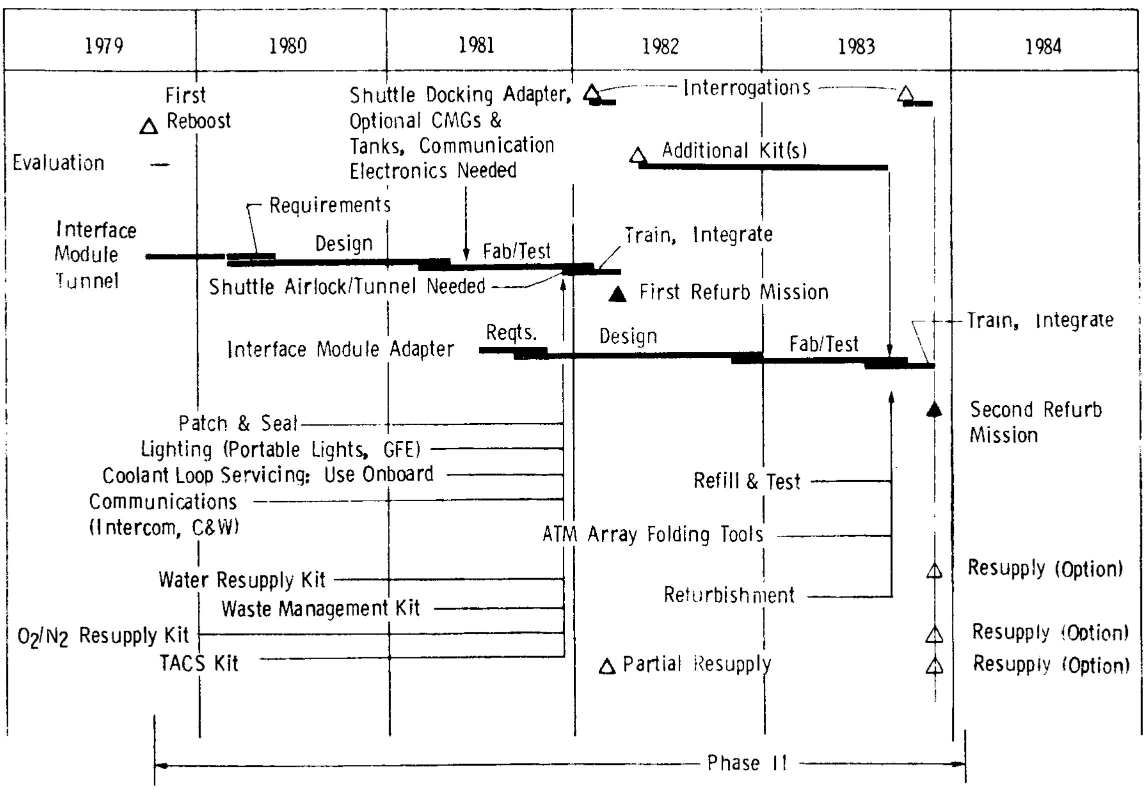


Figure 5-2 Detail--Phase II Schedule (Two-Piece Interface Module)

this figure, the time spans used to spread costs for the refurbishment kits are shown, as are their need dates. With the protoflight approach, kits are needed about three to four months prior to launch for crew training and integration for the mission.

An alternate Skylab reuse program schedule is shown in Figure 5-3. This schedule applies to the case in which 1) refurbishment is delayed until late 1983 and 2) a one piece interface module is built. This alternative allows deferring of funding (compared to the baseline reuse program) for both Skylab and Shuttle hardware/software. The disadvantage of this option is that initial refurbishment is delayed, posing a risk that some of the subsystems will not be ready for reuse when the Power Module is docked in early 1984. Restoration of active CMG/TACS control and early operation of Skylab in 1982 is also not available with this alternative.

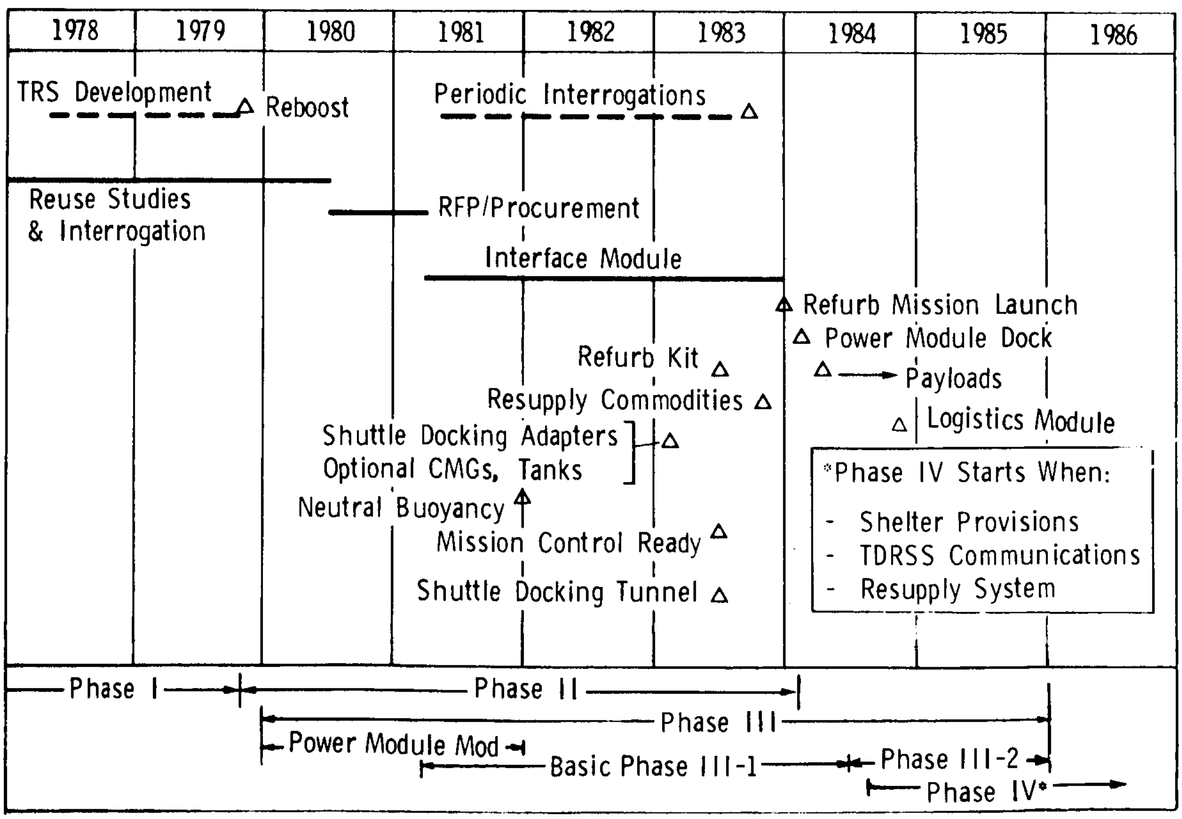


Figure 5-3 Reuse Program Schedule--One-Piece Interface Module in Late 1983

5.2 WORK BREAKDOWN STRUCTURES (WBS)

A Work Breakdown Structure was prepared for each program phase (Figure 5-4). Phase I is the present program phase in which ground interrogation and Reuse Definition Studies are conducted. The primary phases costed are Phase II and Phase III-1 (defined as the mission in which the Power Module is docked to the cluster).

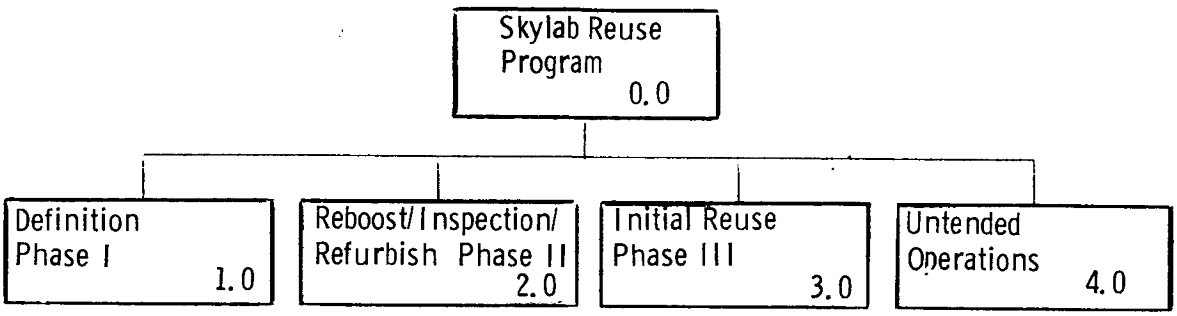


Figure 5-4 Work Breakdown Structure (WBS)

Work Breakdown Structures for each of the four phases are shown in Figures 5-5 through 5-8. The Phase I WBS has two parts which are extensions of current interrogation and study tasks. These are identified but not costed. Phase II contains most of the refurbishment kits. The Interface Module Reboost/TRS (WBS 2.1) refers to Teleoperator Retrieval System modifications (basic design and its transportation are not included). Spacelab Mods (WBS 2.5) apply to trusses and stowage provisions needed to add resupply items to a basic Spacelab module or pallet. No modifications which scar the Spacelab were identified for the resupply function. Shuttle transportation (WBS 2.6) assumes shared transport costs with other payloads.

The Phase III WBS adds modifications to the Power Module (WBS 2.3) based on the MSFC,September 1977 baseline design. Spacelab (WBS 3.4) includes trusses, rotating joints, and interface hardware to attach Spacelab to the Interface Module. Other modifications to the Spacelab for operation in this mode (e.g., forward bulkhead penetrations to route the thermal loop to the power module) were identified but not costed. Mission hardware includes remaining refurbishment kits and tasks needed to reactivate the Apollo Telescope Mount (ATM) and Skylab biomedical experiments.

Phase IV includes sustaining engineering (under SE&I, WBS 4.2) and hardware needed to allow autonomous Ku Band communications through the TDRSS. Project management, as in all four Work Breakdown Structures, is included as a percentage of the other WBS costs.

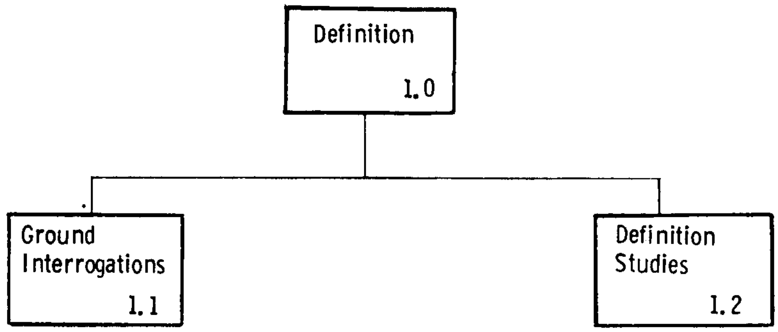


Figure 5-5 Phase I Work Breakdown Structure

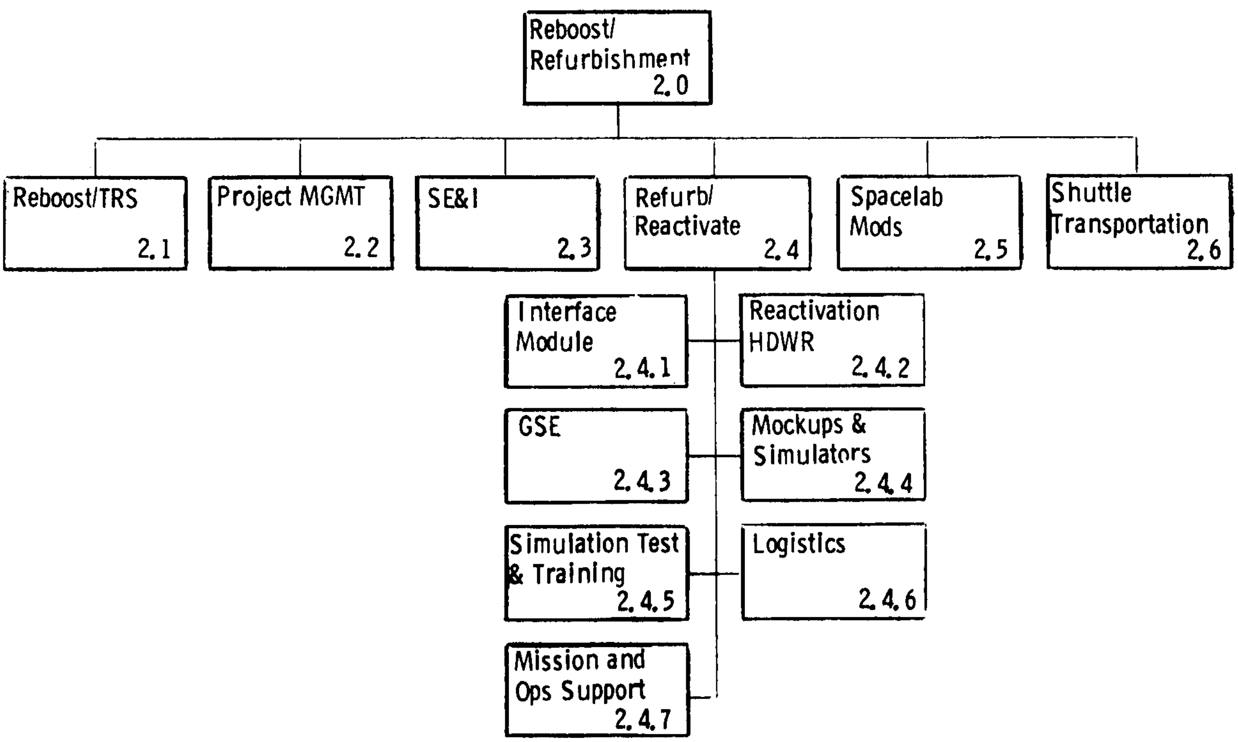


Figure 5-6 Phase II Work Breakdown Structure

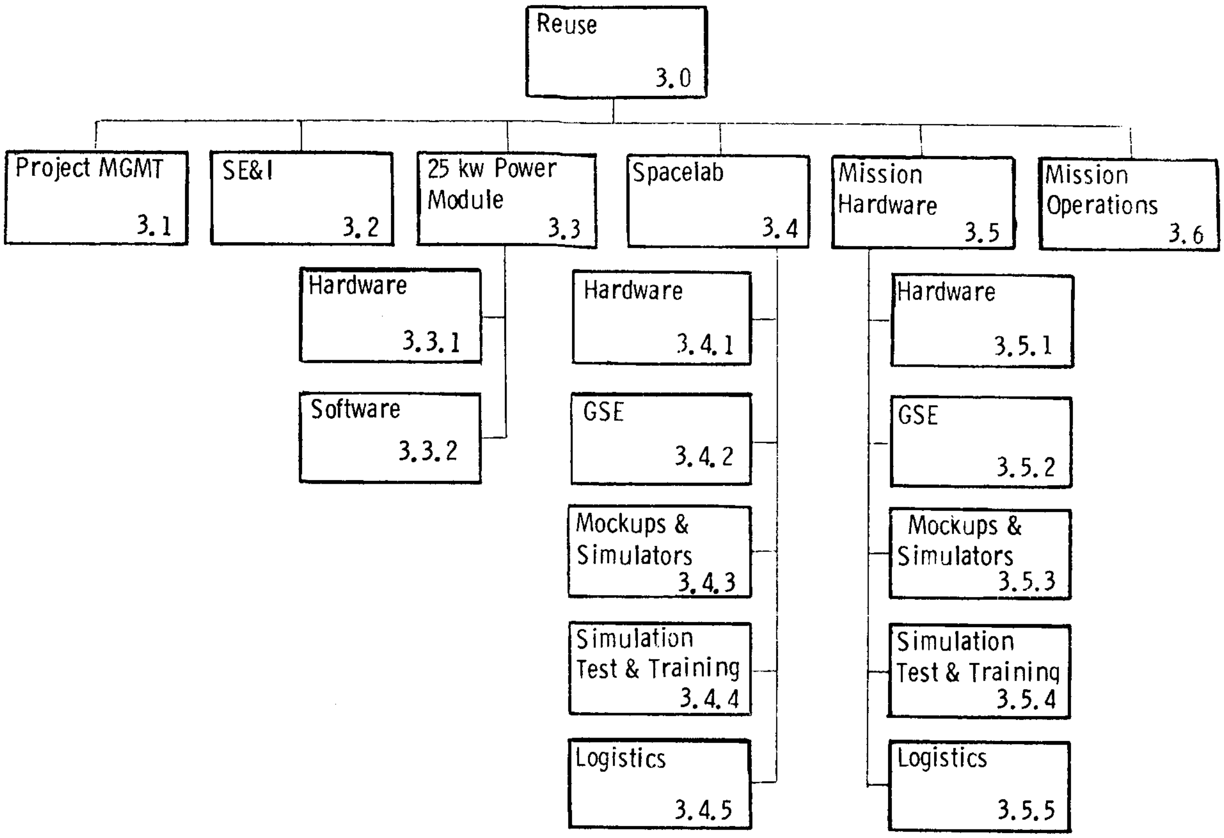


Figure 5-7 Phase III Work Breakdown Structure

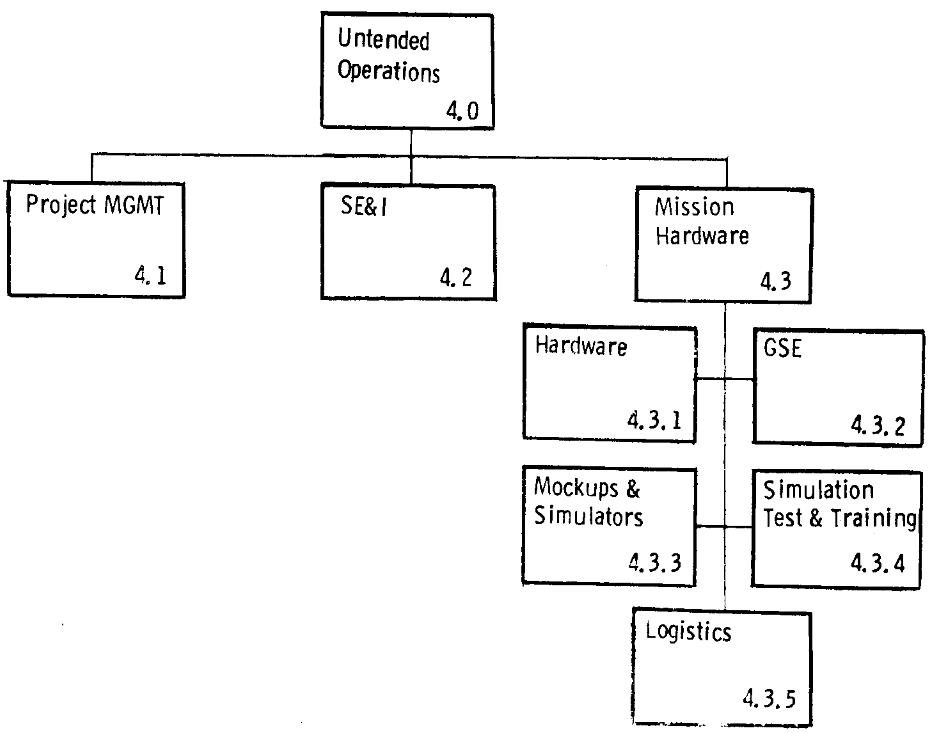


Figure 5-8 Phase IV Work Breakdown Structure

5.3 COST

Our cost estimating approach is shown in Figure 5-9. Technical data define the elements to be costed. Schedules were prepared to support need dates. These were in turn used to spread costs. The basic ground rules from Section 1.0 were supplemented and work breakdown structures derived. Costs were then estimated for each program phase (except Phase I) and cumulative cost curves prepared. At this point in the Reuse Program, a number of options exist such as adding Control Moment Gyros to the Interface Module. Cost,data for these were prepared to support later trade studies.

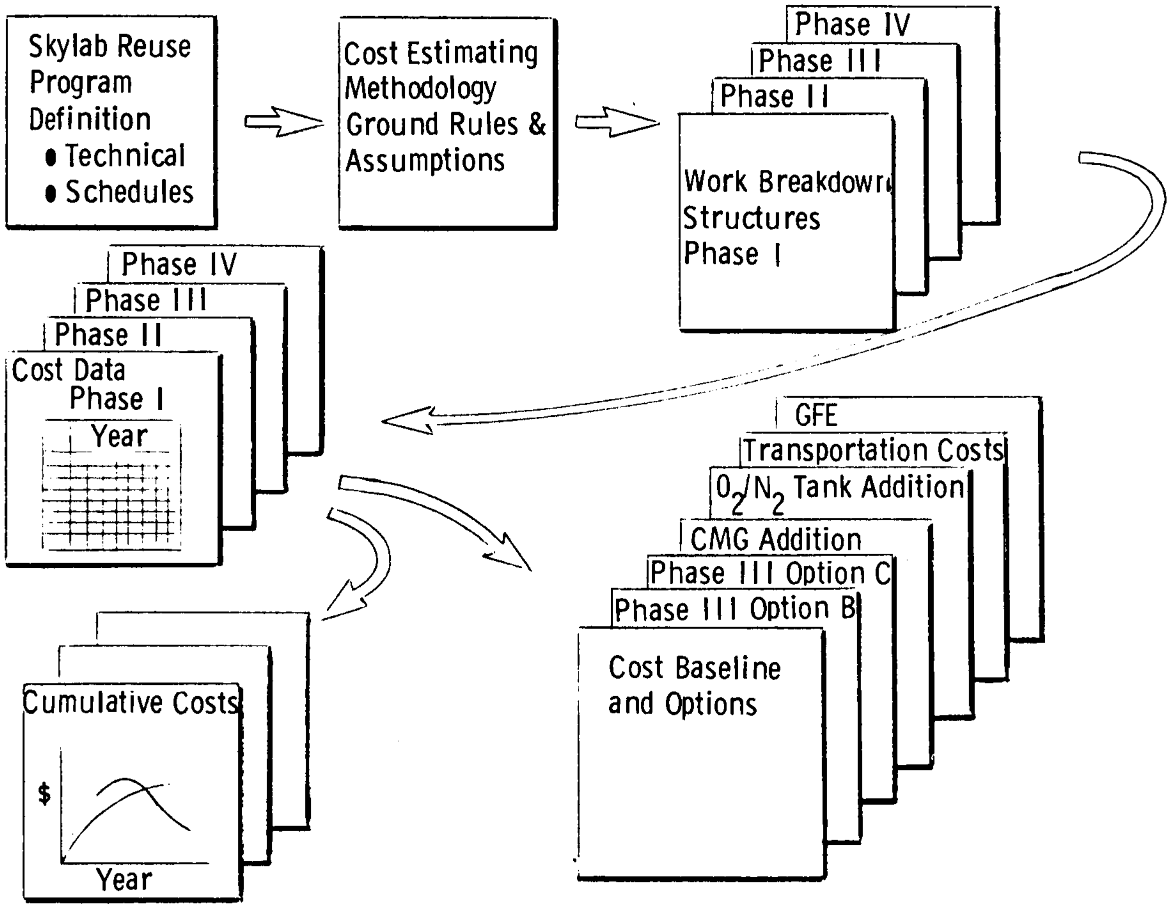


Figure 5-9 Cost Approach

Cost ground rules and assumptions, which supplement Section 1.0 ground rules, are shown in Figure 5-10. These ground rules and assumptions further qualify generated cost data. Two significant items for which costs are not included are consumables (including crew equipment, food, water, and air) and ground software. These should be included in cost estimating tasks in a follow-on study.

All Costs Presented In FY 78 Constant Dollars

No Contractor Fee Included

Consumables Are Not Included

Transportation From Contractors Facilities Is Via GBL

Incorporation Of The Three (3) Additional CMGs On The Power Module Will Be Accomplished During Initial Design And Production Of The Power Module

Phase II Pointing Control/Docking Analysis Performed As Part Of Orbiter Task

Ground Software Costs Not Included

Figure 5-10 Cost Ground Rules and Assumptions

The cost methodology is shown in Figure 5-11. Hardware, logistics, training, simulation, mission operations, and systems engineering and integration needed for refurbishment/reactivation are defined. Costs were generated using techniques shown in the right column. Interface and Logistics Modules were costed using two types of data. First, the RCA price cost estimating model was used. In using the model, input data based on a previous similar structure were entered and complexity factors adjusted until the model matched the previous cost data. Data were then input for the interface and logistics modules. The outputs of the computer model were checked using Cost Estimating Relationships from our Engineering Estimating Handbooks. These handbooks represent a wide range of programs and have been kept current over the last several years.

Refurbishment kit costs were estimated on the project and checked by specialists. Systems Engineering and Integration (SE&I) costs were derived by 1) reviewing the Skylab Job Output List and 2) preparing task statements applicable to Skylab Reuse. Program Management was 10% (the average of four other MMC programs). Mission operations assume small liaison offices at MSFC, JSC, and KSC, with personnel from SE&I, module and refurbishment teams located at the Mission Control facility on a temporary basis. This approach was used on Skylab, and is considered to be applicable to reuse since specialists in each subsystem, who were directly involved in design/analysis/test, also man the consoles. Team size is much reduced from the original Skylab operations team. We provided two specialists per subsystem on the primary shift and one specialist per subsystem on other shifts, with all team members on call. The team size can support this level until near continuous operations are desired. At this point, a dedicated operations team is required.

Define

Hardware Requirements
Modules, Kits

↓

Logistics, Training &
Simulation Requirements

↓

Mission Operations
& SE&I Requirements

Cost

- Modules
  - Price Model
  - Engineering Parametric
- Kits
  - Engineering Estimates from Specialists
- SE&I
  - Discrete Estimates Based on Detail Task Statements
- Program Management
  - Historical Data
- Training
  - Estimates from Crew Training Specialists
- Logistics
  - Estimates from Logistics Specialists
- Mission Operations
  - Basic Support from SE&I Personnel (Similar to Skylab)

Figure 5-11 Cost Methodology

Cost elements for the four program phases are shown in Figures 5-12 through 5-15. Phase I cost elements were identified as shown, but cost estimates were not prepared. Costs would include 1) continuing ground interrogation and subsystem monitoring, and 2) continuation of the present studies to refine present design and cost, resulting in criteria/specifications.

Phase II cost elements (Figure 5-13) are provided for four cases. They are one and two-piece interface module cases, with and without resupply. The refurbishment kits are the same in all cases, but their time spans change. Resupply costs apply to hardware items only, e.g., trusses and rack adapting structure to adapt a Spacelab as a resupply carrier. Consumables are not included.

Phase III cost elements, shown in Figure 5-14, are broken into two parts. Phase III-1 allocates costs to the Power Module flight. This partial phase, when combined with Phase II costs, scope the refurbishment costs. Phase III-2 applies to the payload operations phase between 1984 and 1986. The primary items costed are the sustaining engineering and the Logistics Module. Three kits are shown. The sun shield will be required when payloads require pointing with the Cluster oriented off solar inertial (we assume this in 1984). Crew quarters expansion to 7 adds four sleep stations on the upper deck. Food preparation refers to an option in which the Shuttle galley oven and tray system are added to the wardroom.

Phase IV costs apply to three items: 1) sustaining engineering; 2) a Ku Band communications kit; and 3) program management.

Cumulative costs estimates applying to refurbishment of Skylab are shown in Figure 5-16. The baseline case, containing the two-piece interface module (curve A) will cost slightly over $49 million in constant 1978 dollars. Curve B adds trusses and rack interface structure to Spacelab to adapt it for resupply. The one-piece interface module case, with flight in 1982 (curve C), results in earlier peak funding but lower overall costs. The one-piece interface module case with pallet added for resupply (curve D) defers costs and results in overall costs only slightly higher than the 1982 case (again using constant 1978 dollars)

- Continued Skylab Monitoring and Interrogation
- Follow-on Analysis, Plans, Cost Definition
  - Interface Module Design/Specification
  - Cluster Level System Analyses: Combined Operations
    - APCS
    - EPS
    - I&C/C&W
    - ECS
    - TCS
    - Structural/ Dynamics

    Orbiter/Skylab/I/F Module
    P/L Modules/Logistics Module
    Basic and Growth
  - Systems Engineering to Define Phase II Specifications
  - Refurbishment Kits Design
  - Definition of Long Term Subsystem Monitor, Analysis, Replacement
  - Test Definition & Requirements
  - Mission Operations Definition Including Software
- Performance Period: Present Through 1979

Figure 5-12 Phase I Cost Elements

- Phase II
  - Refurbishment/Reactivation
  - Resupply (Option)
- Four Cases
  1. Baseline Two-Piece Interface Module (Two Missions With Transport Cost Sharing)
  2. Add Resupply To Item 1
  3. One-Piece Interface Module (Two Missions With Transport Cost Sharing)
  4. Add Resupply To Item 3
- Items Costed
  - Program Management
  - Systems Engineering And integration
  - Interface Module
  - Refurbishment Kits
  - GSE
  - Mockups And Simulators
  - Simulation Test And Training
  - Logistics
  - Mission And Operations Support
  - Spacelab Modifications
  - Transportation
- Period of Performance: October 1979 - January 1984

Figure 5-13 Phase II Cost Elements

- Two Parts

  Phase III-I Power Module Docking
  Phase III-2 Operational Period

- Phase III-I Items

  Power Module Mods (3 CMGs + software): 1980 - 1981
  Mission Integration: Late 1981 - Early 1984

- Phase III-2 Items

  Sustaining Engineering to 1986 (Three payload flights integrated)
  Logistics Module: 1981 to 1984 or 1982 to 1985 dependent on Phase II resupply
  Sun Shield
  Crew Quarters Expansion
  Food Preparation

Figure 5-14 Phase III Cost Elements

- Phase IV: Untended Operations, Moving Toward Growth Payloads and Continuous Manning

- Phase IV Costs

  - Ku Band Communications: 1984 - 1985

  - Sustaining Engineering: 1986 - 1987

Figure 5-15 Phase IV Cost Elements

Cost data presented in the curves of Figure 5-16 are detailed in the tables that follow. Costs are broken out by WBS item by year and by phase. Table 5-1 applies to the baseline two-piece interface module case. Transportation costs for the two flights are not included in the tabulated data. These costs are slightly over $33 million, assuming transportation cost sharing, as defined in the Space Transportation System Requirements Guide dated February 1978.

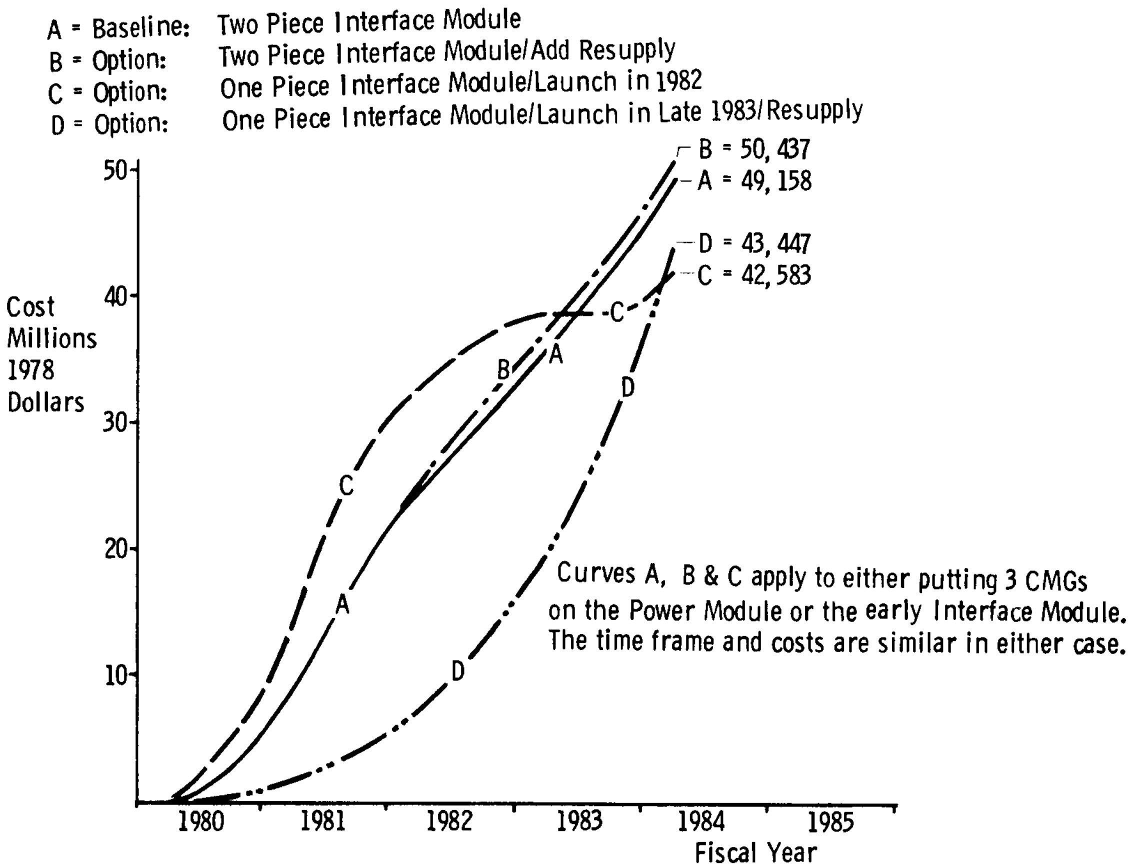


Figure 5-16 CUM Cost Curves: Phases II and III-1

Table 5-1 Baseline (Two-Piece Interface Module)

	FY 80	FY 81	FY 82	FY 83	FY 84	Total
		Phase II				
2.1 Reboost/TRS	-	-	-	-	-	-
2.2 Project MGMT	$ 425	$ 1,282	$ 955	$ 934	$ 111	$ 3,707
2.3 SE&I	2,148	3,325	2,989	2,479	591	11,532
2.4 Refurbish/Reactivate	2,100	9,490	6,558	6,864	516	25,528
Phase II Total	$4,673	$14,097	$10,502	$10,277	$1,218	$40,767
		Phase III-1				
3.1 Project MGMT	$ 85	$ 115	$ 111	$ 195	$ 257	$ 763
3.2 SE&I	-	198	1,002	1,875	2,095	5,170
3.3 25 kw Power Module	849	947	111	-	-	1,907
3.6 Mission Operations	-	-	-	79	472	551
Phase III-1 Total	$ 934	$ 1,260	$ 1,224	$ 2,149	$2,824	$ 8,391
Total Phase II & III-1	$5,607	$15,357	$11,726	$12,426	$4,042	$49,158

Not Included:

Phase II Space Transportation Costs of $33,170

	FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88	Total
		Phase III-2								
3.1 Project MGMT	-	$ 93	$ 755	$ 1,212	$ 728	661	143	-	-	$ 3,592
3.2 SE&I		666	1,899	3,415	4,927	5,482	1,313	-	-	17,702
3.5 Mission Hardware	-	261	5,647	8,702	2,349	1,129	121	-	-	18,209
Phase III-2 Total	-	$ 1,020	$ 8,301	$13,329	$ 8,004	$7,272	$1,577	-	-	$ 39,503
		Phase IV								
4.1 Project MGMT	-	-	-	-	$ 723	$ 27	$ 443	$ 591	$ 148	$ 1,932
4.2 SE&I	-	-	-	-	-	-	3,939	5,252	1,313	10,504
4.3 Mission Hardware	-	-	-	-	7,230	270	495	660	165	8,820
Phase IV Total	-	-	-	-	$ 7,953	$ 297	$4,877	$6,503	$1,626	$ 21,256

Table 5-2 breaks Phase II costs out to the third level WBS. The two-piece interface module costs can be seen: $16.5M.

Table 5-2 Baseline Program Cost (Two-Piece Interface Module)

WBS	Task	Description	Cost (Millions) PH II	PH III-1
2.2 / 3.1	Project Management	Cluster Level & Hardware Project Mgmt	3.707	.763
2.3 / 3.2	Systems Engineering & Integration	Cluster Level SE&I	11.532	5.170
/ 3.3	25 KW Power Module Mods	Add 3 CMGs, Software	--	1.907
2.4.1	Interface Module	Two Piece: Tunnel & Adapter	16.508	--
2.4.2	Reactivation Hardware	Refurb Kits	1.987	--
2.4.3	Ground Support Equipment	MGSE / EGSE	.511	--
2.4.4	Mockups & Simulators	Ig &Neutral Bouyancy Hardware	.404	--
2.4.5	Simulation Test & Training	Ig & Neutral Bouyancy Test/Training Support	2.004	--
2.4 6	Logistics	Ground Crew Training, Transportation	2.076	--
2.4.7 / 3.6	Mission Operations Support	Support at MSFC / JSC / KSC	2.038	.551
		Sub Total	40.767	8.391
			49.158	
2.6	Shuttle Transportation	Two Flights (Shared Cost Basis)	33.170	--

NOTE: All Costs in Constant 1978 Dollars

Hardware costs for refurbishment, including kits and logistics module, are shown in Table 5-3. Costs to refurbish the subsystems are low, especially when compared to costs of building a new space station.

As stated earlier, three options to the baseline case were defined, as well as a number of subsystem hardware options. Table 5-4 shows the breakout by WBS of the case which includes a one piece interface module flown in 1982 (curve C on Figure5-16). This is the lowest cost case evaluated. One reason for the low cost is the requirement for only one Shuttle flight. This results in less integration, training, logistics, simulations and program management.

Table 5-3 Other Hardware Costs

Phase II	
ATM Array Folding	$ 64 K
Coolant Loop Servicing	89
Water Resupply	401
Waste Management	160
O_2 / N_2 Recharge	716
TACS Recharge	443
Patch and Seal	102
Power Transfer	101
Phase III-2	
Logistics Module	14,468 K
Sun Shield	385
Food Prep	273
Addn'l Crew Quarters	374
Communications	125
Phase IV	
Ku Band	$ 7,000 K

Table 5-4 Option (One-Piece Interface Module/Launch in 1982)

	Phase II	Fy'80	Fy'81	Fy'82	Fy'83	Fy'84	Total
2.1	Reboost/TRS	--	--	--	--	--	--
2.2	Project Mgmt	$ 619	$ 1,919	$ 570	--	--	$ 3,108
2.3	SE&I	$2,148	$ 3,325	$2,599	--	--	$ 8,072
2.4	Refurbish/Reactivate	$4,046	$15,868	$3,098	--	--	$23,012
	Phase II Total	$6,813	$21,112	$6,267	--	--	$34,192
	Phase III-1						
3.1	Project Mgmt	$ 85	$ 115	$ 111	$ 195	$ 257	$ 763
3.2	SE&I	--	$ 198	$1,002	$1,875	$2,095	$ 5,170
3.3	25 KW Power Module	$ 849	$ 947	$ 111	--	--	$ 1,907
3.6	Mission Operations	--	--	--	$ 79	$ 472	$ 551
	Phase III-1 Total	$ 934	$1,260	$1,224	$2,149	$2,824	$ 8,391
	Total Phase II & III-1	$7,747	$22,372	$7,491	$2,149	$2,824	$42,583

Not Included: Phase II Space Transportation Cost $21,760

Table 5-5 shows the program case in which resupply is added to the second refurb mission of the two piece interface module. In this case, trusses to mount oxygen, nitrogen, and water tanks are added to two standard Spacelab pallets. The pallets require no scarring to add the trusses, resulting in significant resupply at a relatively nominal increase in cost.

Table 5-5 Option (Two-Piece Interface Module/Add Resupply)

	Phase II	Fy'80	Fy'81	Fy'82	Fy'83	Fy'84	Total
2.1	Reboost/TRS	--	--	--	--	--	--
2.2	Project Mgmt	$ 420	$ 1,302	$ 975	$ 1,014	$ 111	$ 3,827
2.3	SE&I	$2,148	$ 3,325	$ 2,989	$ 2,429	$ 591	$11,532
2.4	Refurbish/Reactivate	$2,100	$ 9,490	$ 6,558	$ 6,864	$ 516	$25,528
2.5	SpaceLab Mods	--	$ 196	$ 197	$ 766	--	$ 1,159
	Phase II Total	$4,673	$14,313	$10,719	$11,123	$1,218	$42,046
	Phase III-1						
3.1	Project Mgmt	$ 85	$ 115	$ 111	$ 195	$ 257	$ 763
3.2	SE&I	--	$ 198	$ 1,002	$ 1,875	$2,095	$ 5,170
3.3	25 KW Power Module	$ 849	$ 947	$ 111	--	--	$ 1,907
3.6	Mission Operations	--	--	--	$ 79	$ 472	$ 551
	Phase III-1 Total	$ 934	$ 1,260	$ 1,224	$ 2,149	$2,824	$ 8,391
	TOTAL Phase II&III-1	$5,607	$15,573	$11,943	$13,272	$4,042	$50,437

Not Included: Phase II Space Transportation Cost $55,550

The program case corresponding to curve D in Figure 5-16 above is detailed in Table 5-6. This case has a one-piece Interface Module loaded internally with resupply items plus two pallets in the payload bay, which carry water, oxygen, and nitrogen. As in the two piece interface module case, significant initial resupply can be provided at a nominal increase in cost.

Transportation costs for the four cases are shown in Table 5-7. The one-piece interface module, with its single flight, has the lowest cost. However, adding resupply to either the two piece or one piece interface modules provides the lowest cost initial resupply.

Table 5-6 Option (One-Piece Interface Module/Launch in Late 1983/Resupply)

WBS II III-1	Task	Description	Cost (Millions) PH. II	PH. III
2.2 / 3.1	Project Management	Cluster Level & Hardware Project Mgmt	3.186	.763
2.3 / 3.2	Systems Engineering & Integration	Cluster Level SE&I	8.072	5.170
/ 3.3	25 KW Power Module Mods	Add 3 CMGs, Software	--	1.907
2.4.1	Interface Module	One Piece	16.130	--
2.4.2	Reactivation Hardware	Refurb Kits	1.987	--
2.4.3	Ground Support Equipment	MGSE/EGSE	.511	--
2.4.4	Mockups & Simulators	lg & Neutral Buoyance Hardware	.404	--
2.4.5	Simulation Test & Training	lg & Neutral Buoyancy Test/Training Supt.	1.403	--
2.4.6	Logistics	Ground Crew Training/Transport	1.454	--
2.4.7/3.6	Mission Operations Support	Support at MSFC/JSC/KSC	1.123	.551
2.5	Spacelab Mods	Pallet Trusses	.786	--
		Sub Total	$\underbrace{35.056 \quad 8.391}_{43.447}$	
2.6	Shuttle Transportation	Two Flights (Shared Cost Basis)	26.970	--

Table 5-7 Transportation Cost Comparison

	Cy 1982	Cy 1983
Baseline: Two Piece Interface Module	18.23M	14.94M
Option: Two Piece Interface Module With Resupply	24.06M	31.49M
Option: One Piece Interface Module Launch In 1982	21.76M	* Resupply In 1984 After PM Plight
Option: One Piece Interface Module Launch Late In 1983 With Resupply		26.97M

Some hardware items are assumed available as GFE. Table 5-8 lists our assumptions in this regard. Costs for these items are excluded.

Table 5-8 GFE Assumptions

1. 3 CMGs (for refurb by Bendix)
   For Either the Power Module or the Optional Modification to the Interface Module
2. O_2 Tanks (Skylab)
   For the Logistics Module, the Optional Modification to the Interface Module and the Optional Modification to the Spacelab Pallets (resupply)
3. N_2 Tanks (Skylab)
   For Logistics Module and the Optional Modification to the Spacelab Pallets (resupply)
4. H_2O Tanks (Skylab)
   For Logistics Module and the Optional Modification to the Spacelab Pallets (resupply)
5. Compatibility Test Van STDN No. 101.3
   For Ground Support and Checkout of Communications
6. Neutral Buoyancy Facilities and Skylab Hardware
7. Communication Hardware
   - Spacelab High Rate Mux
   - Spacelab High Rate Digital Recorder
   - CSM OMNI Antennas
   - CSM Transmitter
   - CSM Transponder
   - CSM Pre-modulation Processor
   - CMD Detector and Decoder
8. New Experiments Equipment

Selected options were also costed. Table 5-9 shows the cost of reworking and operating the Skylab ATM and biomedical experiments. These costs include integration into mission sequences, crew training, procedure preparation, coordination with principal investigators, and definition of resupply consumables. The consumables themselves (e.g., film in the case of the ATM) are not included.

Table 5-9 Cost Options

Phase III Option B: Adding Capability for Selected Skylab Experiments and/or Selected OWS/MDA Experiments and/or Selected MDA/ATM Experiments.

Cost Impact:	Update of ATM for Reuse	=	\$ 558K
	Biomedical Experiments Reuse	=	\$ 454K
	Total Cost		\$1,012

Three other cost options are shown in Table 5-10. Three CMGs must be added to the cluster, either in the Power Module or on the Interface Module. Software to control CMG operation will also be required. If the CMGs are integrated into either module early in the development cycle (e.g., early 1980 in the case of the Power Module), impact on design should be small and the cost of adding CMGs should be about the same.

Oxygen and nitrogen tanks can be added to either the one or two piece interface module as another option. The costs are the same in either case; only the funding years change.

Table 5-10 Costs for CMG and O_2/N_2 Tank Additions

- Adding 3 CMGs To Either the Two (2) Piece Interface Module (Tunnel Section) Or the Optional One (1), Piece Interface Module

Cost Impact	FY 80	FY 81	FY 82	FY 83	Total
	\$934K	\$1,042K	\$ 122K	--	\$2,098

- Adding O_2N_2 Tanks to the Two (2) Piece Interface Module (Docking Adapter Section)

Cost Impact	FY 80	FY 81	FY 82	FY 83	Total
Phase III	--	\$ 30K	\$172K	\$ 231K	\$433K

- Adding O_2 N_2 Tanks to the Optional One (1) Piece Interface Module

Cost Impact	FY 80	FY 81	FY 82	FY 83	Total
Phase II	\$108K	\$228K	\$97K	--	433K

Spacelab modules/pallets will be removed from the Orbiter cargo bay and attached to the Interface Module in either Phase III or Phase IV. Hardware will be required to allow this transfer including one or more of the cases shown in Table 5-11. The items costed are

Table 5-11 Spacelab Interface Hardware Costs

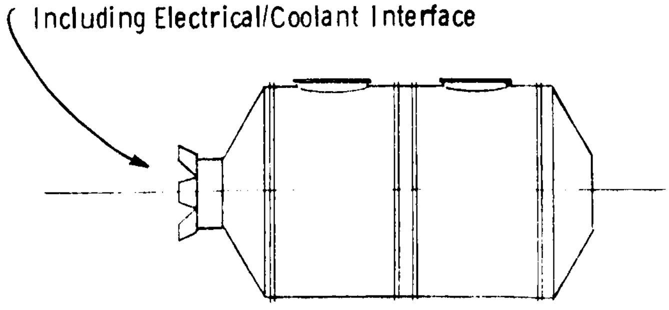
Phase III Option C: Adding Capability for New Docked/Berthed Spacelab Modules and Experiments Operated in a Shuttle Tended Mode. Five (5) Spacelab Hardware Alternatives are Presented.

Baseline:	Spacelab Module to Interface Module Docking Port Including Electrical/Coolant Interface
Alternate One:	Baseline Plus a Fixed Truss to Accommodate Attaching Spacelab Pallet(s)
Alternate Two:	Spacelab Pallet(s) to Interface Module Docking Port and Fixed Truss
Alternate Three:	Spacelab Pallet(s) to Interface Module Docking Port and Rotating Joint/Truss
Alternate Four:	Baseline Plus a Rotating Joint/Truss to Accommodate Attaching Spacelab Pallet(s)

shown in Figure 5-17 for each of the five cases. Some modifications will be required to basic Spacelab structure or on board equipment (e.g., bulkhead penetrations for thermal loops connecting with the Power Module for heat rejection). Basic modifications to Spacelab hardware are not costed here.

Phase III Option C Baseline

Spacelab Crew Module to Interface Module Docking Port Including Electrical/Coolant Interface



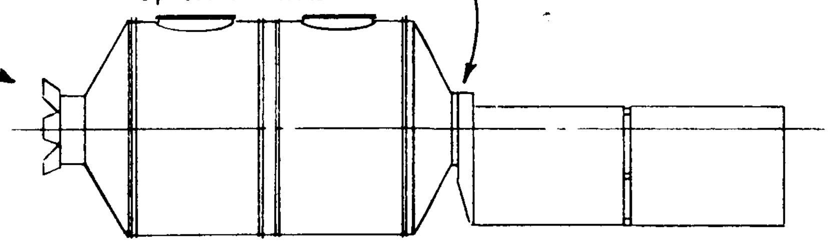
Cost Impact $2,432K

Spacelab Module Rental Not Included

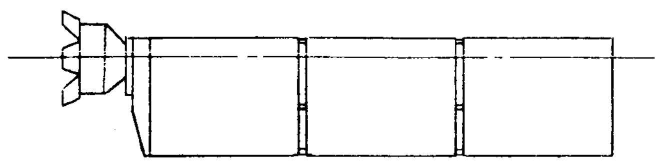
Figure 5-17 Spacelab Interface Hardware Costs

Phase III Option C Alternates One or Two

Alternate One: Baseline Plus a Fixed Truss to Accommodate Attaching Spacelab Pallets

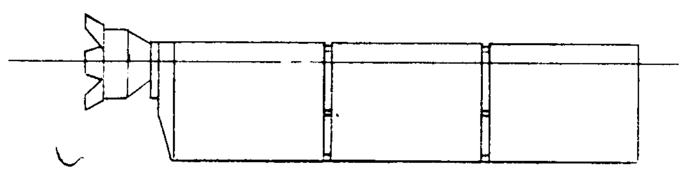


Alternate Two: Spacelab Pallet(s) to Interface Module Docking Port and Fixed Truss

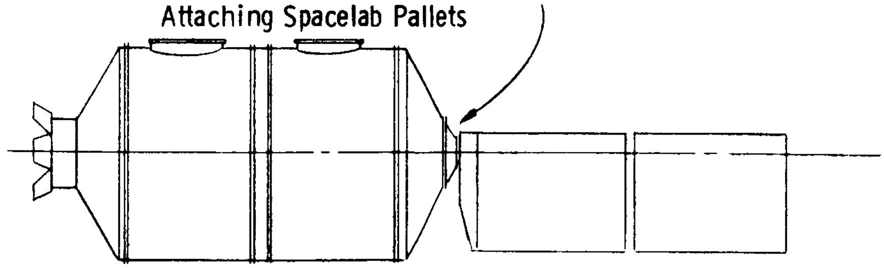


Cost Impact: Either Alternate $3,091K
Spacelab Rental Not Included

Alternate Three: Spacelab Pallet(s) to Interface Module Docking Port and Rotating Joint/Truss



Alternate Four: Baseline Plus a Rotating Joint/Truss to Accommodate Attaching Spacelab Pallets



Cost Impact: Either Alternate $4,004K
Spacelab Rental Not Included

Figure 5-17 (Concluded)

6.0 CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER PROGRAM DEFINITION

6.1 Conclusions

6.1.1 Utility

Our study shows that Skylab has high utility as a Space Platform for habitability and payloads as presented below:

<u>Habitability</u>

- o Few repairs needed; consumable resupply restores habitability
- o Large volume: accommodates basic and expanded crews and IVA experiments
- o Skylab continuous untended operations with:
  - Ku Band Communications addition
  - Logistics Resupply System
  - Shelter provided in Interface Module

<u>Payloads</u>

- o All payload disciplines accommodated
- o ATM reuse possible with film resupply
- o Skylab biomedical experiments require resupply; no repairs identified
- o Prime Skylab use: Long duration payloads, periodically or continuously manned
- o Store payloads on cluster, reducing boost frequency and transport costs
- o Skylab orbit accommodates 70 - 80% of Spacelab type payloads

Skylab is the largest volume spacecraft flown, with about 10,000 ft^3 of internal volume in the OWS alone. This volume exceeds that needed for three crewmen based on tests and sizes of other manned vehicles both in space and on earth. Large volume allows expansion of crew size to 6 or 7, with space still available for IVA experiments. We have made conceptual layouts which show that life sciences and materials sciences experiments can be moved in and operated on the OWS upper deck. With the large volume available, many zero g IVA activities can be undertaken.

Skylab should provide long duration operations untended by the Shuttle a short time from initial operations in 1984. Three prequisites are needed: 1) Autonomous Ku Band communications through the TDRSS to the ground must be added to the Skylab cluster; 2) logistics resupply capability must be established; and 3) shelter for the crew must be established. In the latter respect, the Interface Module configurations shown in the report can provide the shelter for 7 crewmen. Analysis shows that supplies should be provided for 10 days of shelter time. This duration is based on time needed to turn around a shuttle mission (plus contingencies) and launch it in a rescue mode to Skylab.

Payload requirements were compared to cluster capabilities. All payload disciplines can be operated from Skylab, including those requiring stellar, earth, and solar pointing. Control system analysis shows that the equivalent of 5 CMGs plus a spare will provide the necessary cluster pointing. Space processing, life sciences, and space construction payloads are readily accommodated. Since they have few pointing requirements, the cluster can be oriented to maximize power, thermal control capability, and communications through TDRSS. Skylab provides a strongback function for construction of large structures. For example, the demonstration articles for solar power and communications defined in recent space station studies can be built and operated from Skylab. Demonstration of the Space Spider construction technique is particularly suited to Skylab. Space crane operation plus joining, aligning, fastening, refueling and other techniques for construction and transfer of payloads to geosynchronous orbit can be evaluated from Skylab.

As an added benefit, partially completed payloads and/or payload modules/pallets can be stored attached to Skylab. This feature can allow both manned and unmanned operation and substantially reduce the transportation costs of delivering these payloads to and from orbit on a short duration, frequent basis. Skylab, in this mode, becomes a national facility for payload operation and evaluation. Analysis of Spacelab type payloads shows that 70 to 80% of the payloads can be accommodated from the Skylab orbit.

6.1.2 Assessment For System Reactivation

The assessment for system reactivation encompassed subsystem status and refurbishment kits, required missions and resupply. A summary of reactivation conclusions are presented below:

Subsystem Status And Refurbishment Kits

- o Subsystems operable: Power Module supplements power, provides CMG control
- o CMGs on Interface Module restore original performance
- o Eleven refurbishment kits; no new technology

Missions

- o TRS needed for stabilization on 1st mission if TACS/CMGs unavailable
- o Stabilization, refurbishment kit installation, significant resupply possible in one mission
- o Resupply TACS on 1st mission for stability on next mission

Resupply

- o Interface Module plus 1- 2 pallets allow relatively inexpensive initial resupply
- o Logistics Module significantly cheaper than Spacelab resupply in operational use

Ground interrogation combined with analysis indicates the vehicle subsystems are operable. Space has proven a good place to store equipment since few components have failed and little repair appears necessary.

The baseline Power Module definition (MSFC, September 1977) used for this study has three control moment gyros. Five are required for control, with the sixth as a spare. Three CMGs must therefore be added to the cluster. An attractive option is the one addition of the three CMGs to the Interface Module. This can restore original Skylab control system performance prior to Power Module delivery and can allow removal of the Power Module later for other uses or repair.

Refurbishment identified to date, and significant initial resupply can be accomplished in a single mission. It is likely that the Teleoperator Retrieval System (TRS) will be needed to stabilize Skylab for the first refurbishment mission (if existing CMGs are inoperative and TACS depleted). Our analysis shows that payload weight and length is compatible with TRS for this purpose and the TRS can be used without modification. A reboost of Skylab is also possible, if desired. We recommend that the TACS nitrogen be a least partially recharged during the first refurbishment mission, so that Skylab can be stabilized without TRS for later dockings. Tanks for the TACS recharge can be used later to store nitrogen for crew shelter purposes.

Analysis of logistics resupply to Skylab considered three cases: 1) Use of Spacelab; 2) Use of a dedicated Logistics Module; and 3) initial resupply using the Interface Module and pallets. The dedicated Logistics Module will be significantly less expensive than Spacelab resupply in operational use. Use of the Interface Module plus pallets will provide significant initial resupply (up to 320 man-days) at relatively low cost compared to Spacelab or the dedicated Logistics Module.

6.1.3 Interface Hardware/Design Concepts

A summary of conclusions for interface hardware/design concepts are presented below:

<u>Interface Module</u>

- o Simple tunnel section of two-piece module provides low cost, low risk early operation
- o One piece module provides lower transportation cost
- o Both module concepts provide adequate shelter for untended mode
- o Can provide payload module attachment at both Skylab and Orbiter cabin pressures
- o Add control interface electronics to interface with Power Module computer

<u>Power Module</u>

- o Add software to control 3 CMGs in Interface Module in combination with 3 CMGs in the Power Module

The Interface Module is the major piece of hardware needed for Skylab reactivation. Use of a single tunnel section of the two-piece module provides low cost, low risk early operation. The one-piece module results in lower overall costs. Both module concepts provide adequate shelter volume.

Concern was expressed by those associated with the Life Sciences payload discipline about operation of these experiments at 5-to-7 psi. Interface Modules can be configured to provide both

Shuttle and Skylab pressure areas, with the transfer airlock between them. Life sciences payloads can be berthed to the high pressure side allowing both orbital and ground control subjects to be operated with the same sea level pressure.

6.1.4 Programmatics

Summary conclusions involving programmatics are presented below:

Schedules

- o Implement Power Module changes in early 1980 prior to detailed design phase
- o Deliver refurbishment kits 3-4 months before launch for training and integration
- o Provide Shuttle docking module and mission control late 1981 for 1982 flight
- o Procure CMGs early in 1980 for 1982 flight

Cost

- o Skylab provides lowest cost space station alternative
- o Costs to refurbish are $42.6 to 49.2 M in 1978 dollars (without transportation)
- o One-Piece Interface Module provides lowest cost program
- o Two-Piece Interface Module provides greater flexibility, lower early costs for 1982 refurbishment flight
- o Interface Module and pallet(s) provides lowest cost initial resupply

Schedules were prepared for Skylab refurbishment hardware and software. Changes to the Power Module should be identified and initiated in early 1980 to avoid redesign costs. The Shuttle Docking Module and mission control facilities/software will be needed late in 1981 for a 1982 refurbishment mission. If the 1983 refurbishment launch option is chosen, these items can be delayed until mid-1983. Refurbishment kits must be delivered 3-to-4 months before launch for crew training and integration. Control moment gyros must be procurred early in 1980 for the 1982 flight.

Based on the cost data presented in this report, it is clear that reactivation of Skylab provides the lowest cost space platform alternative. Costs to refurbish the vehicle are $42.6 to 49.2 million in 1978 dollars (plus transportation). This is a fraction of the cost of a new space station, based on recent studies. The One-Piece Interface Module case provides the lowest cost program. The Two-Piece Interface Module case provides greater flexibility and lower early costs for a 1982 refurbishment flight.

6.2 Recommendations For Further Program Definition

This study 1) defined subsystem status (based on ground interrogation and analysis); 2) scoped interface and performance requirements, refurbishment kits, number of missions, and the ability of Skylab to accommodate payloads; and 3) defined the resulting cost and schedules. The study concluded that reuse of Skylab is feasible and, relative to building a new space platform, inexpensive. The next step is to carry the program definition to the point that program plans, specifications and baseline operations plans can be prepared/defined. Recommended follow-on items are shown in Figure 6.2-1.

- Continued Skylab Monitoring and Interrogation
- Follow-on Analysis, Plans, Cost Definition
  - Interface Module Design/Specification
  - Cluster Level System Analyses: Combined Operations — Orbiter/Skylab/I/F Module; P/L Modules/Logistics Module; Basic and Growth
    - APCS
    - EPS
    - I&C/C&W
    - ECS
    - TCS
    - Structural/Dynamics
  - Systems Engineering to Define Phase II Specifications
  - Refurbishment Kits Design
  - Definition of Long Term Subsystem Monitor, Analysis, Replacement
  - Test Definition & Requirements
  - Mission Operations Definition Including Software
- Performance Period: Present Through 1979

Figure 6.2-1 Recommendations for Further Program Definition

Several Interface Module configurations were defined, with a two-piece module emerging as the baseline. Further design is needed to reach a firm specification point and selection of a one versus two-piece configuration. The specification must define performance, interface, and crew shelter/safety requirements. The degree of on-orbit outfitting (scarring) must also be determined.

Systems engineering and integration analyses, started on this study should be continued. Computer programs exist in most areas. These need to be activated and analyses performed, particularly to define the interface effects of the new Cluster configuration, i.e., Shuttle, Skylab, Interface Module, Payload Modules, Logistics Module and growth capabilities. Analysis examples are shown in Section 3.1.8 above.

Refurbishment kit design should be continued, resulting in preliminary design drawings and updated interface and installation definition. Subsystems should be investigated for long term maintenance and replacement. Existing spares should be cataloged, systems evaluated for on-orbit access and replaceability, and the plan for long term maintenance prepared. The technique should be similar to the one developed for our Phase B Space Telescope study and subsequent proposal.

A set of trades should be made to further define the lowest cost approach to a refurbishment mission(s). This should then be reflected in a Baseline Operations Plan, defining both mission and ground operations. Software costs should be developed, since they can comprise a significant part of reuse costs. This study identified Power Module, software modification and cost.

Ground software was addressed but not costed due to impending changes in Shuttle system ground software. The Work Breakdown Structure should be revised and costs further developed.

An approach to testing of the on-orbit systems/refurbishment kits after installation should be developed. The test analysis should identify test requirements including impact on interfaces.

Program documentation should be defined and a documentation tree included in the program plan. It should be possible to streamline the documentation relative to the original Skylab program.

Appendix A

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